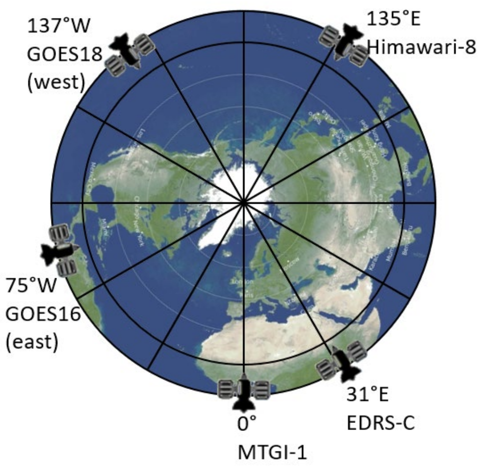

GSICS ANNUAL MEETING

GSICS
Global Space-based
Inter-Calibration System

Cross-calibration of ESA radiation monitors

Ingmar Sandberg

SPACE APPLICATIONS & RESEARCH CONSULTANCY

SPARC, GREECE

17-21 March
Changchun, China

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Acknowledgments

DATASETS/DISCUSSIONS

- **H. Evans, P. Jiggens, M. Heil, ESA Technical officers**
- **B. Kress , J Rodriguez, NOAA, USA (GOES/SGPS)**
- T. Nagatsuma, NICT, Japan (Himawari-8/SEDA)
- Y. Miyoshi, N. Higashio, T. Mitani et al, JAXA (Arase, XEP, HEP)
- T. Onsager, J Rodriguez, A. Boudouridis et al, NOAA, USA (GOES/MPSHI)
- K. Ryden, University of Surrey, UK (Giove-A/SURF, GSAT/EMU)
- D. Baker, S. Claudepierre, A. Boyd, USA, (RBSP/ECT datasets)

SPARC Team

- I. Sandberg
- C. Papadimitriou
- S. Aminalragia-Giamini

Relevant funding

- SSA NGRM Data Processing ESA Contract No 4000127954/19/D/CT
- Cross Calibration EMU Dataset with RBSP, 4000135823/21/NL/GLC/mkn
- European Contribution to International Radiation Environment Near Earth (IRENE) Modelling System, ESA Contract 4000127282/19/NL/IB/gg with SPARC
- SSA NGRM Data Processing ESA Contract No 4000127954/19/D/CT
- Global Radiation Belt Prototype for LEO constellations, 4000137689/22/NL/CRS with ONERA (A. Sicard)

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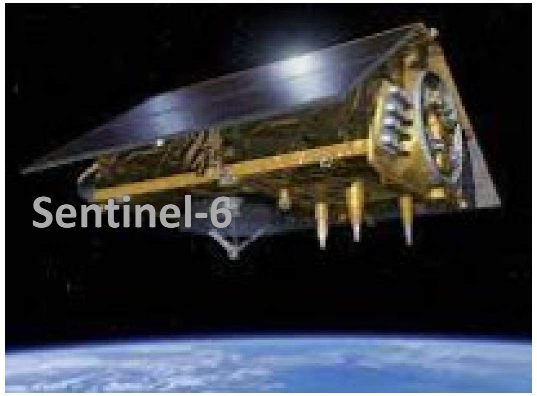
esa esoc european space operations centre

Outline

- ESA radiation Monitors under consideration
- Reference dataset and considerations
- Results accounting proton sensors
- Results accounting electron sensors (GSICS 2023-2024)
- Conclusions

Motivation: calibrate ESA monitors



- In-flight validation/calibration of ESA radiation monitors
- Creation of high-level data products (Level-2)

- **GEO EDRS-C: 31 East**
- **LEO Sentinel-6**
- **GEO MTG1: 0 East**
- **GEO MTG-S1**
- **ERSA Lunar Gateway**

… + more to come

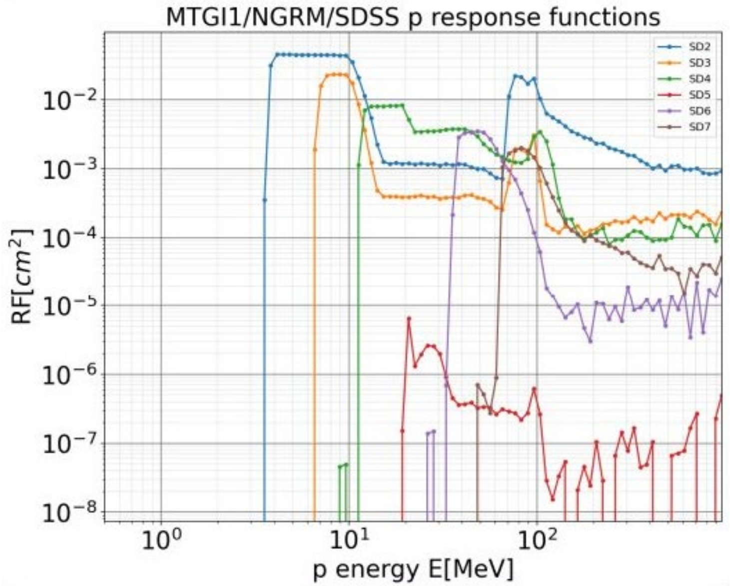
- **GNSS GSAT-0207**
- **GNSS GSAT-0215**

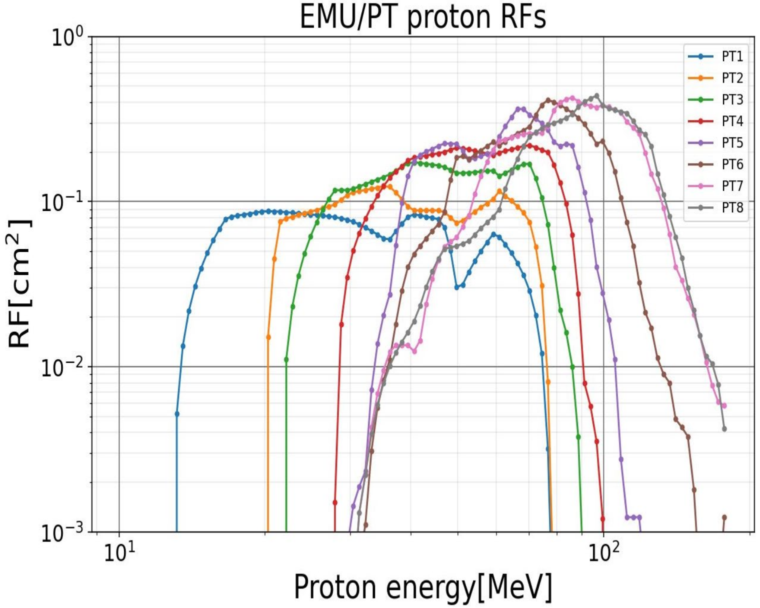
OBS: the sensors PT and SURF of GSAT/EMU and Himawari /SEDA are identical!

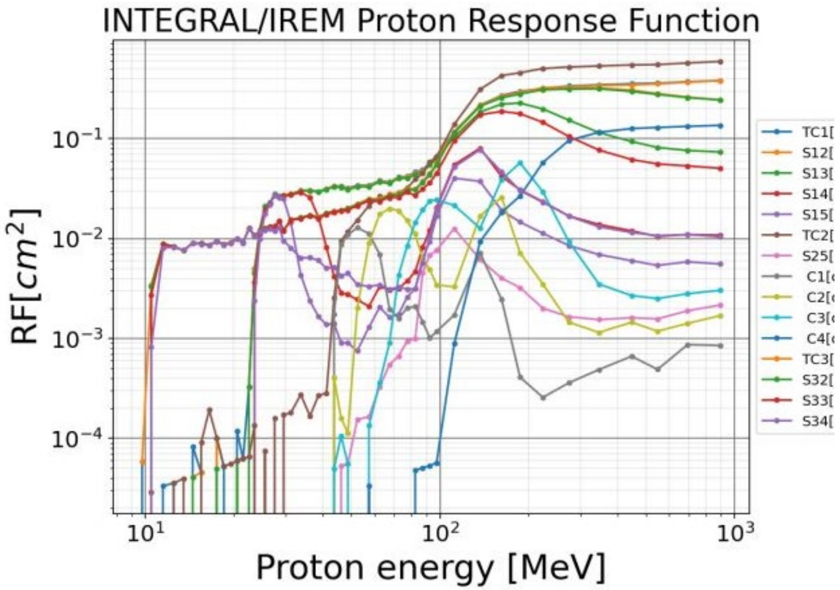
- **HEO INTEGRAL**
- **LEO PROBA-1**
- **GNSS Giove-B**

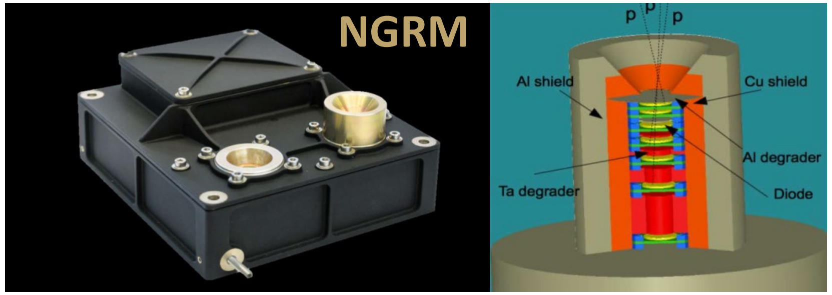
…. + more

Radiation Monitors proton sensors/datasets







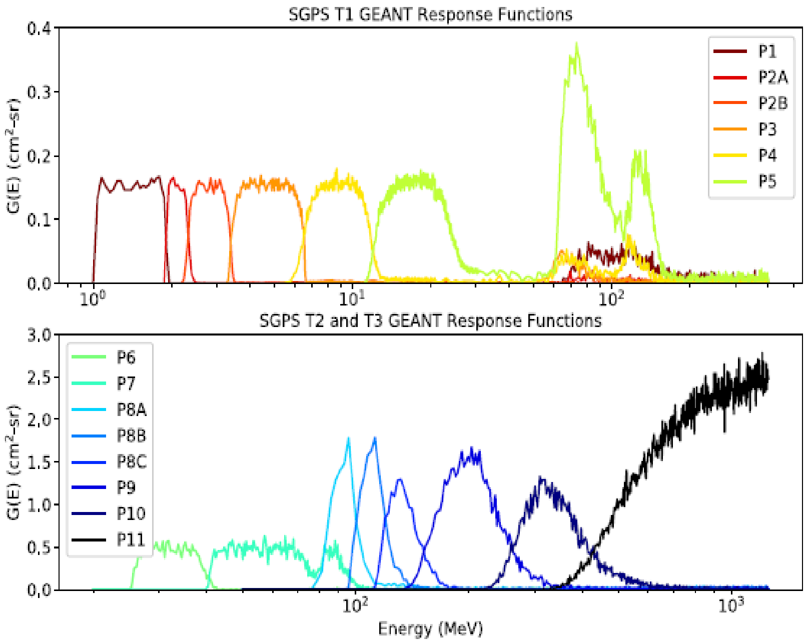


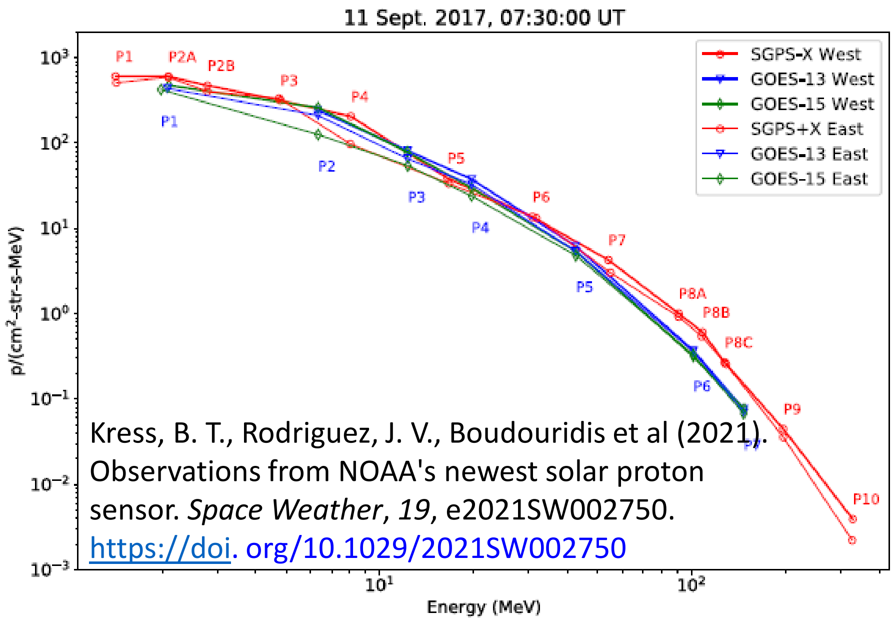
“Reference” dataset: GOES-18/SGPS Solar and Galactic Proton Sensor

We have performed a series of evaluation studies based on comparisons between actual count-rates during Solar Proton Flux Enhancements and count-rates derived using reference fluxes and monitors RFs

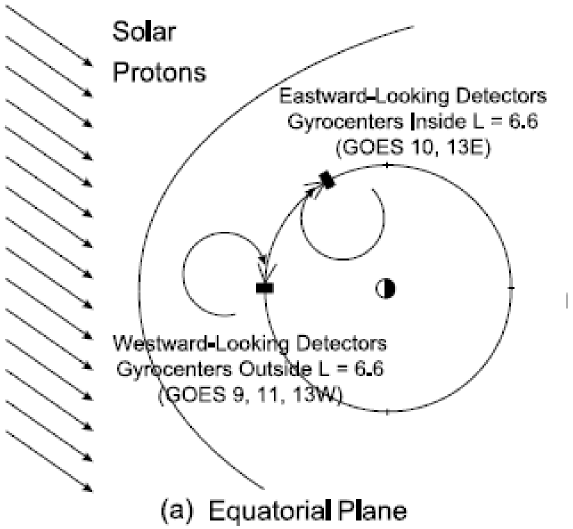
$$C_i = \sum_{q=p,e} \int_0^\infty f_q(E) RF_{i,q}(E) dE$$

J. V. Rodriguez, T. G. Onsager, J. E. Mazur, The east-west effect in solar proton flux measurements in geostationary orbit: A new GOES capability, Geophysical Research Letters https://doi.org/10.1029/2010GL042531



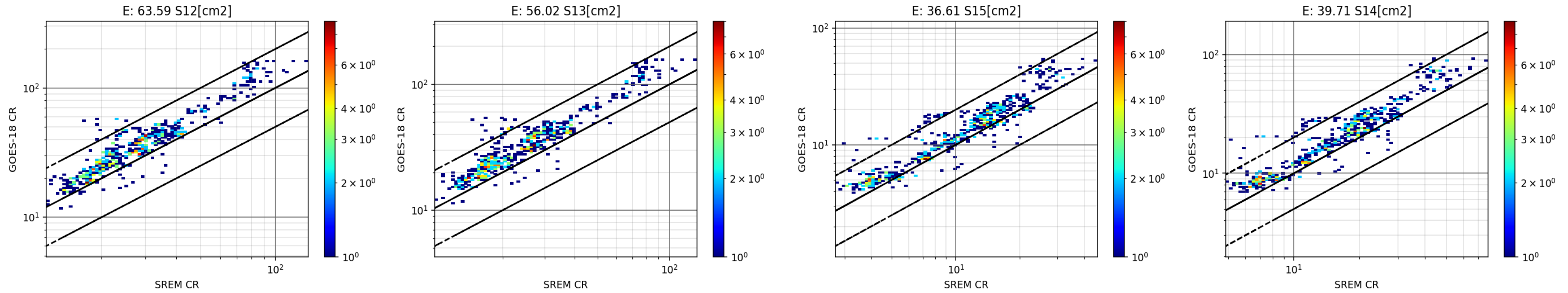


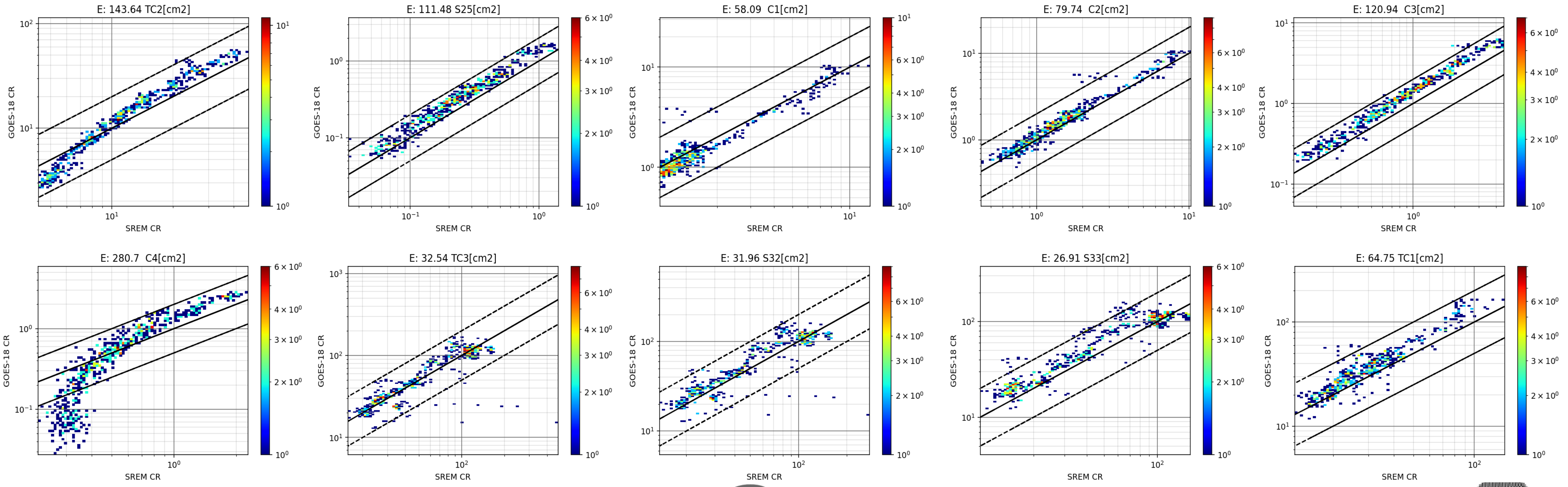
Kress, B. T., Rodriguez, J. V., Boudouridis et al (2021). Observations from NOAA's newest solar proton sensor. *Space Weather*, *19*, e2021SW002750. https://doi. org/10.1029/2021SW002750



INTEGRAL/IREM vs GOES-18/SGPS-WEST CRs

2002-2025





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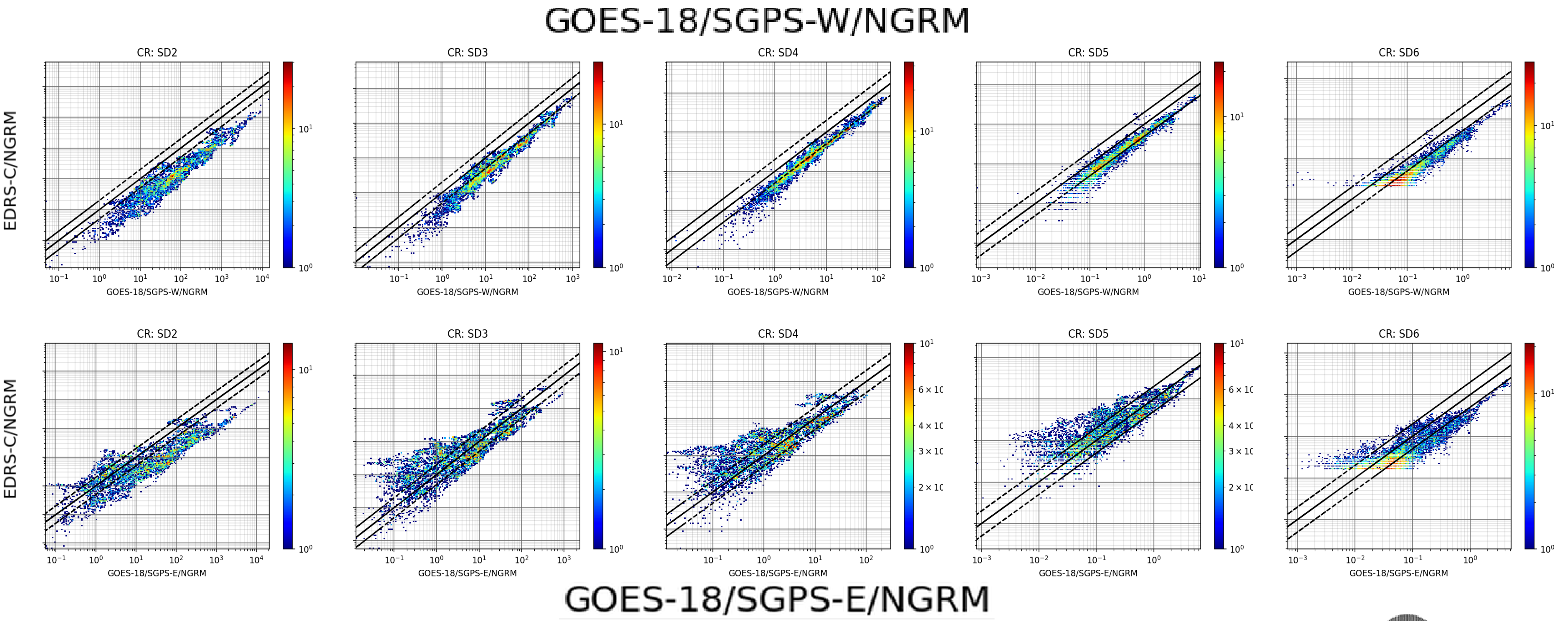
GEO EDRS-C/NGRM vs GOES-18/SGPS



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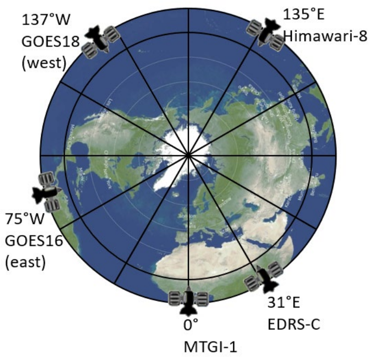
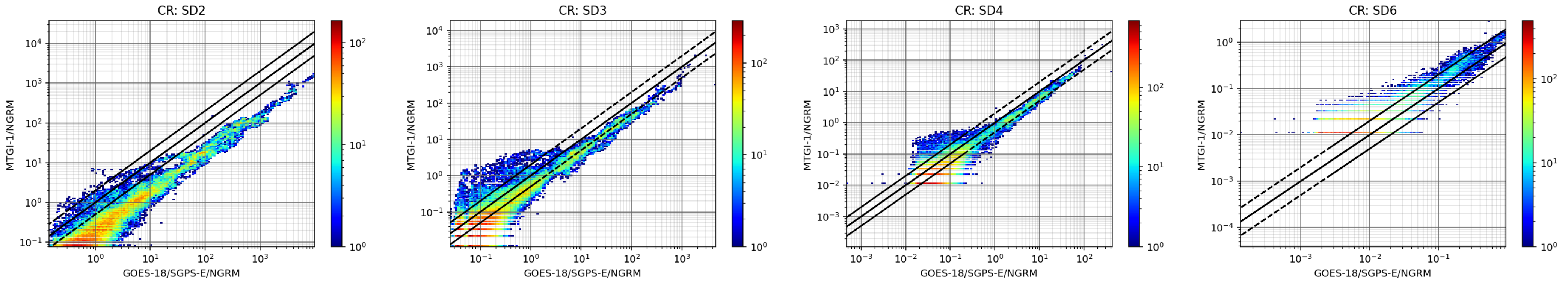
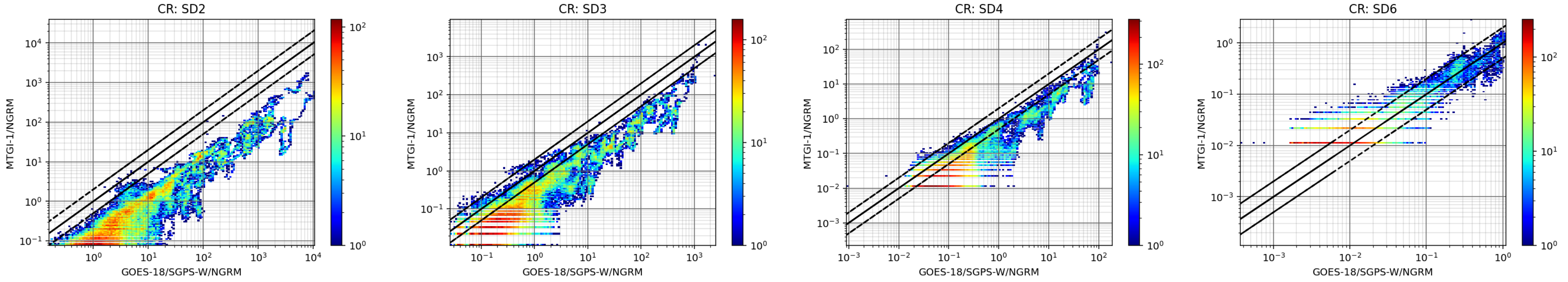
GEO MTGI-1/NGRM vs GOES-18/SGPS



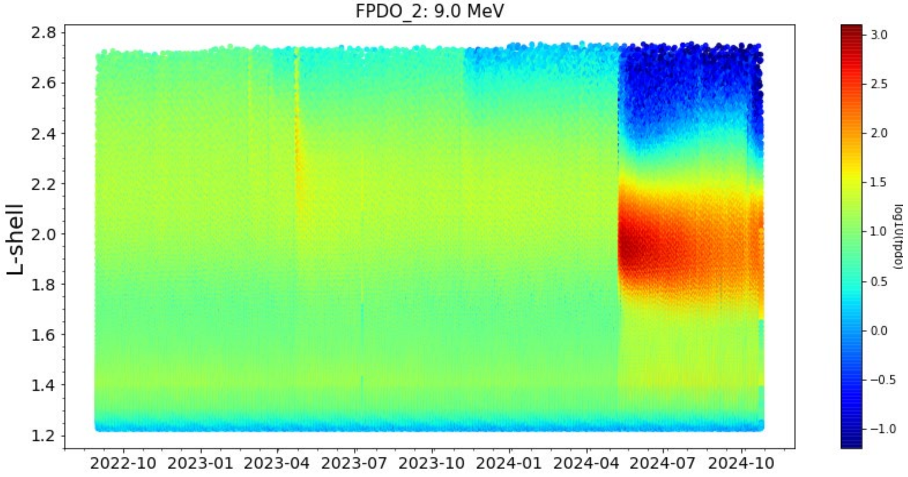
GOES-18/SGPS-E/NGRM

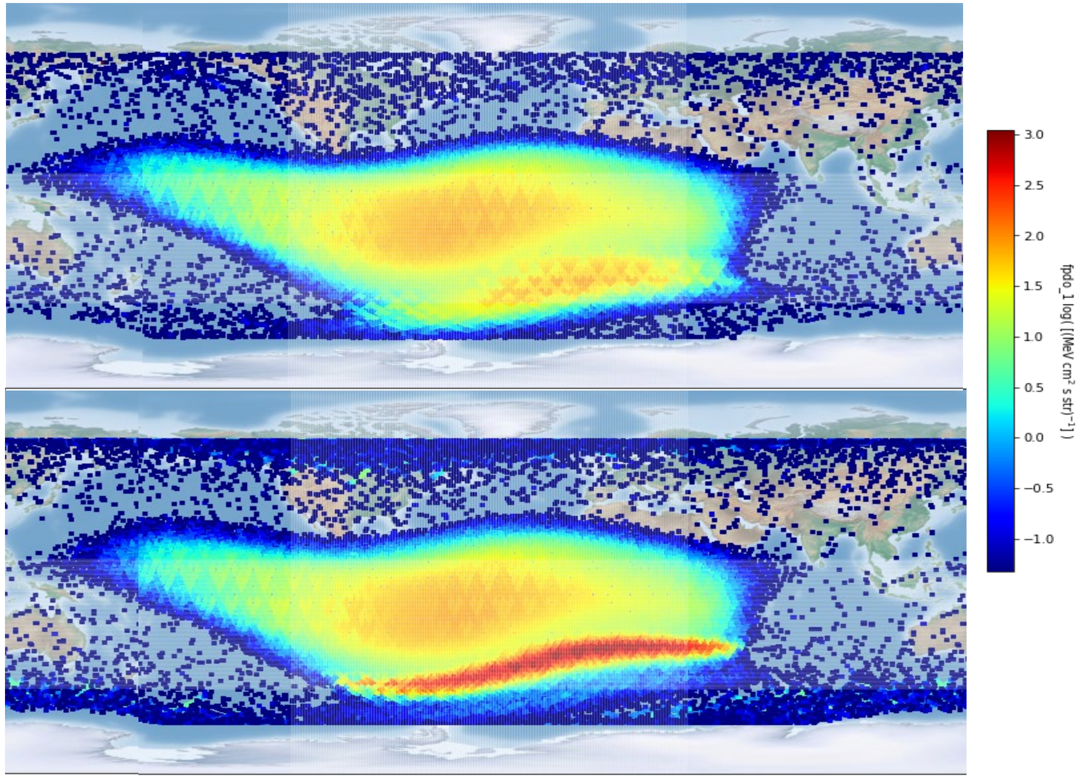




GOES-18/SGPS-W/NGRM

Sentinel-6/NGRM

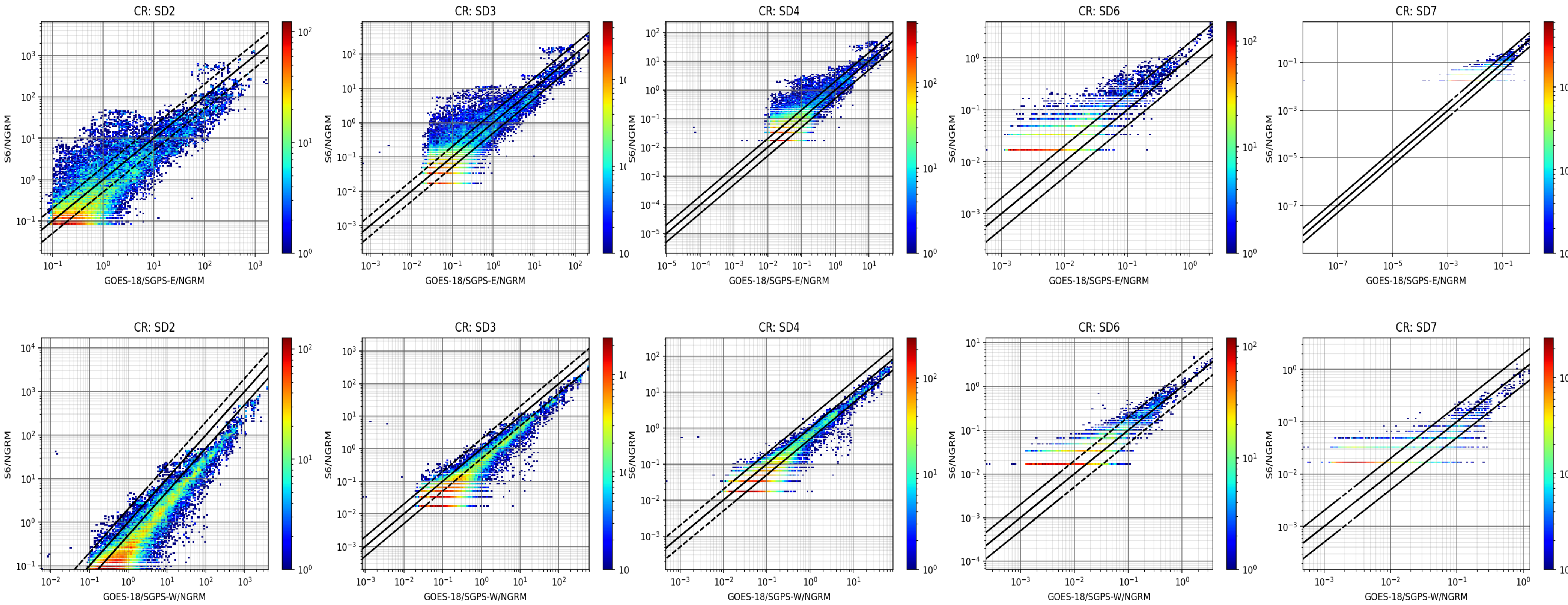




- non sun synchronous orbit
- Altitude: 1,336 km
- Inclination: 66.0°
- NGRM cadence: 15 sec
- Latency: 6 hours

Sentinel 6/NGRM vs GOES-18/SGPS

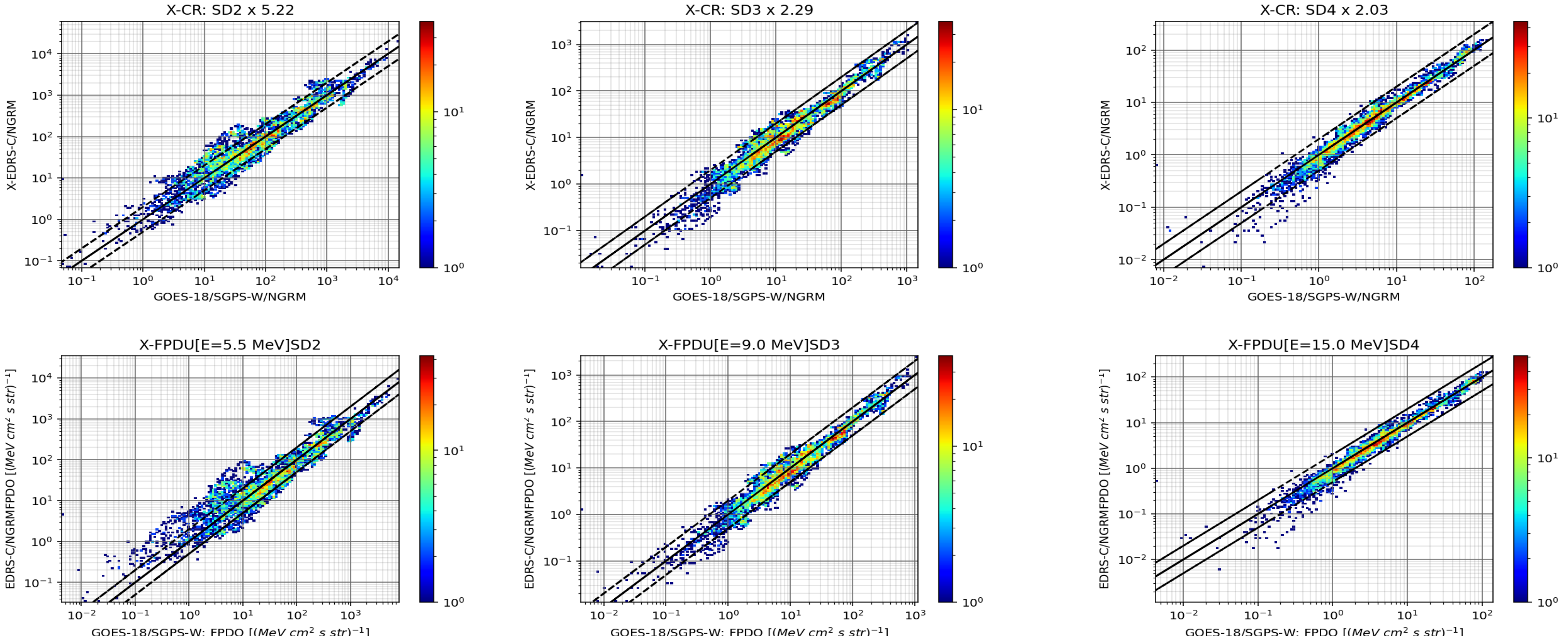
GOES-18/SGPS-E/NGRM



GOES-18/SGPS-W/NGRM

Cross-calibrated ERSC-NGRM proton fluxes

✓ **Apply the cross-calibration factors to the Bow-Tie derived proton fluxes and compare with SGPS fluxes**



Cross-calibrated ERSC-NGRM proton fluxes

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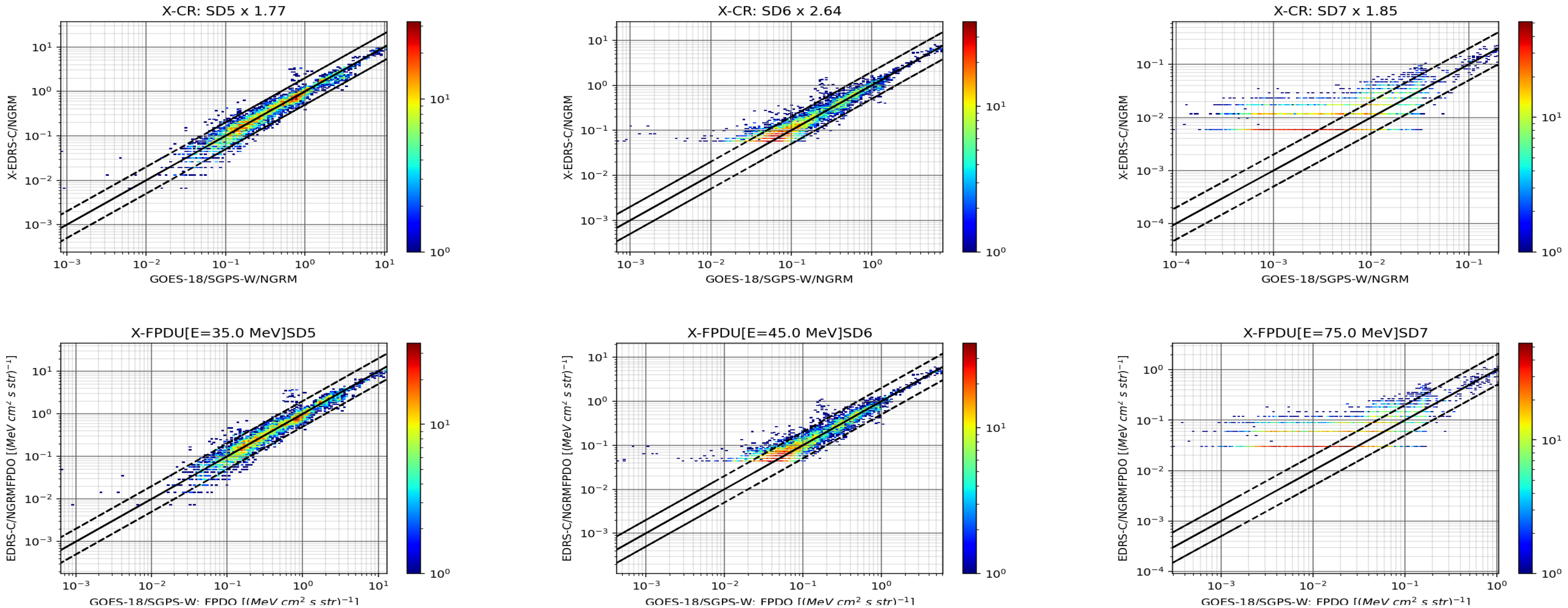

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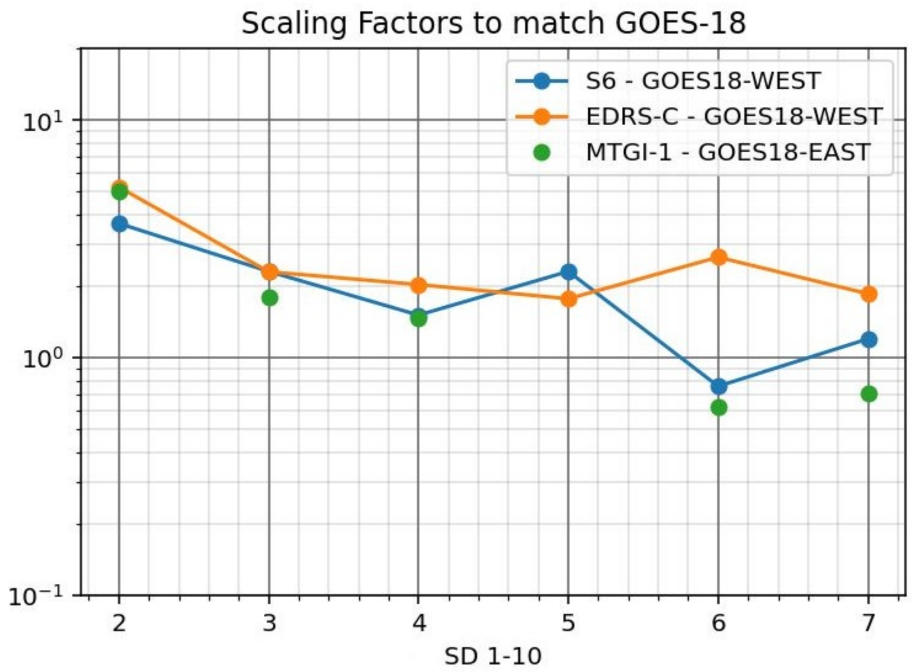
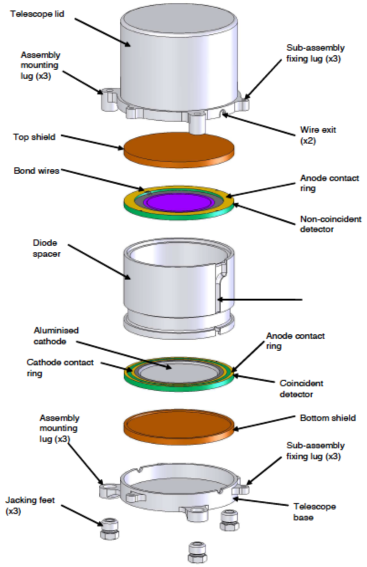
NGRM/SDSS: conclusions

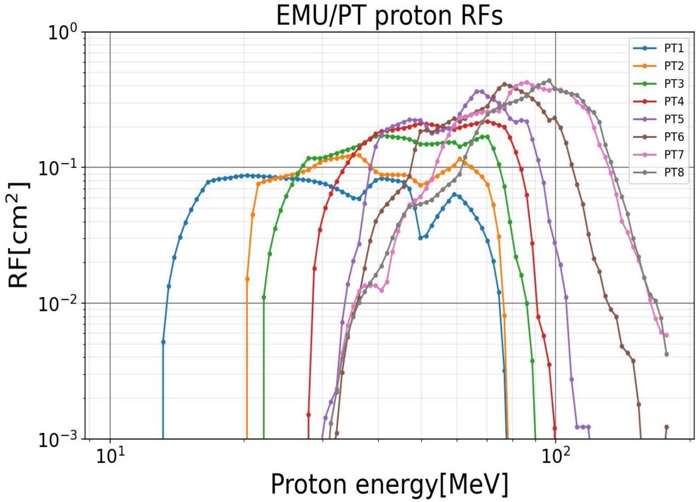
- NGRM protons sensors on-board Sentinel-6 and EDRS-C can be cross-calibrated with west-looking GOES SGPS telescopes
- NGRM proton sensor on-board MTGI-1 can be cross-calibrated with EAST looking GOES SGPS telescopes
- MTGI-1 and EDRS-C NGRM units act as an EAST and WEST looking telescopes for East 0-31 degrees at GEO
- Cross-calibrated NGRM/BT fluxes agree with SGPS



GSAT/EMU/PT

- 8 Proton telescopes

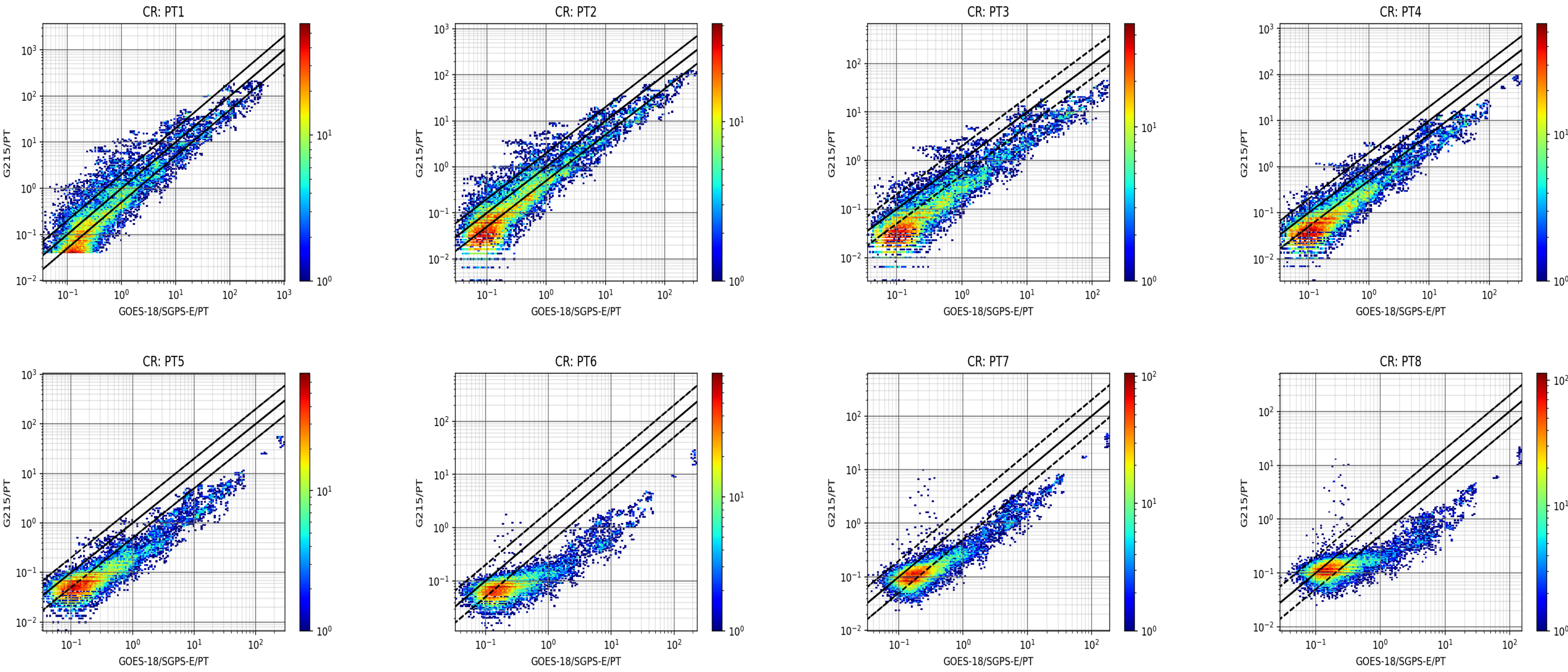




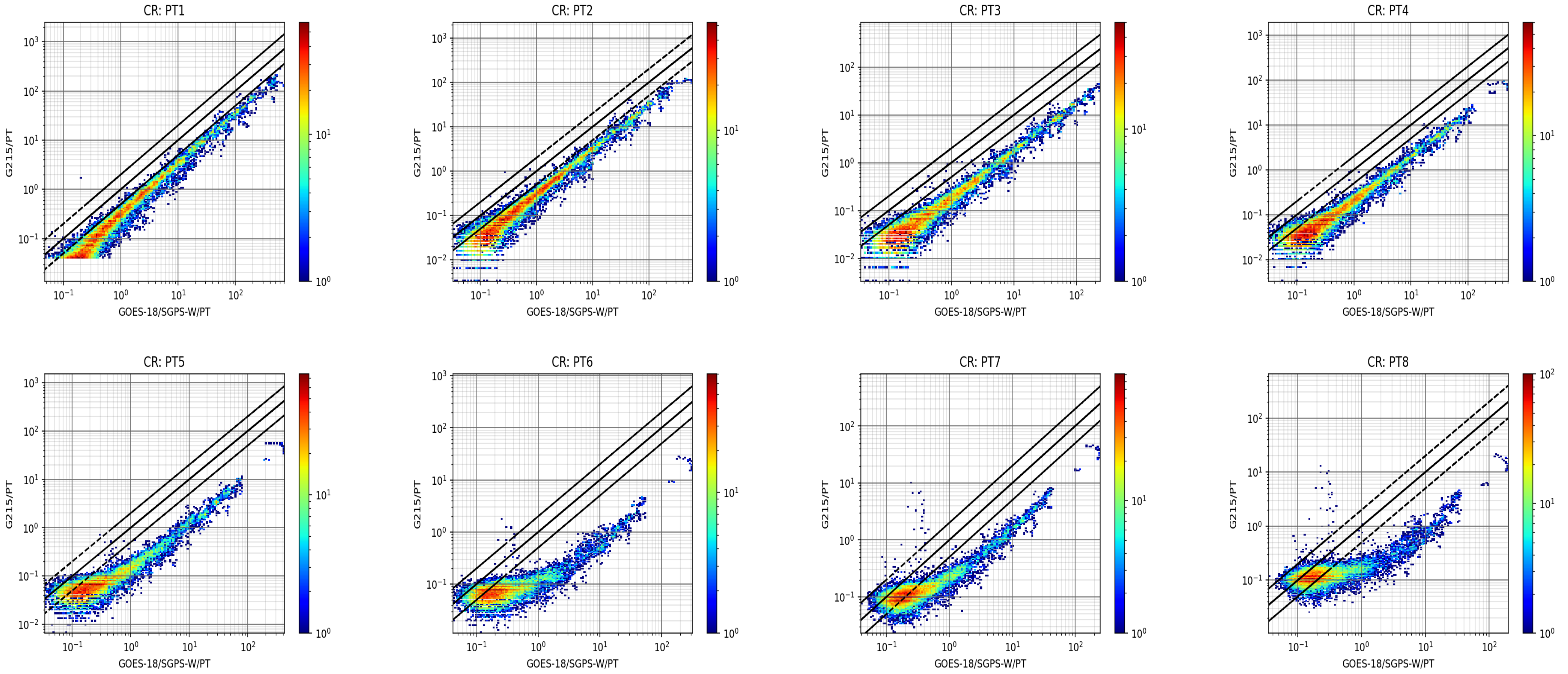
- Limited validations of GSAT207/PT were performed in the past
- L1 products were derived just at the end of the last SC: 1-2 SPEs available at that time

PT	E_{BT} [MeV]
1	22.8
2	29.8
3	36.8
4	42.7
5	49.7
6	59.4
7	67.0
8	71.1

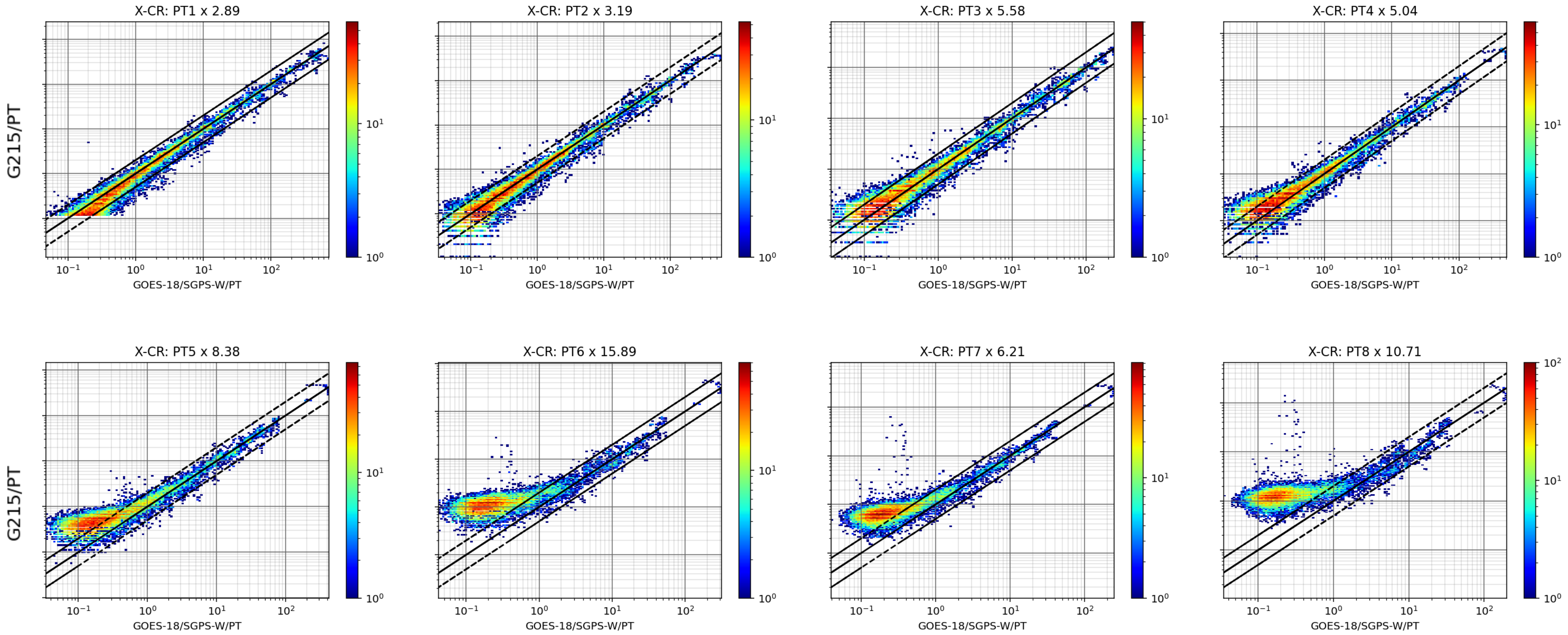
GSAT215/EMU/PT vs GOES-18/SGPS-EAST CRs



GSAT215/EMU/PT vs GOES-18/SGPS-WEST CRs



X-GSAT215/PT vs GOES-18/SGPS-WEST CRs



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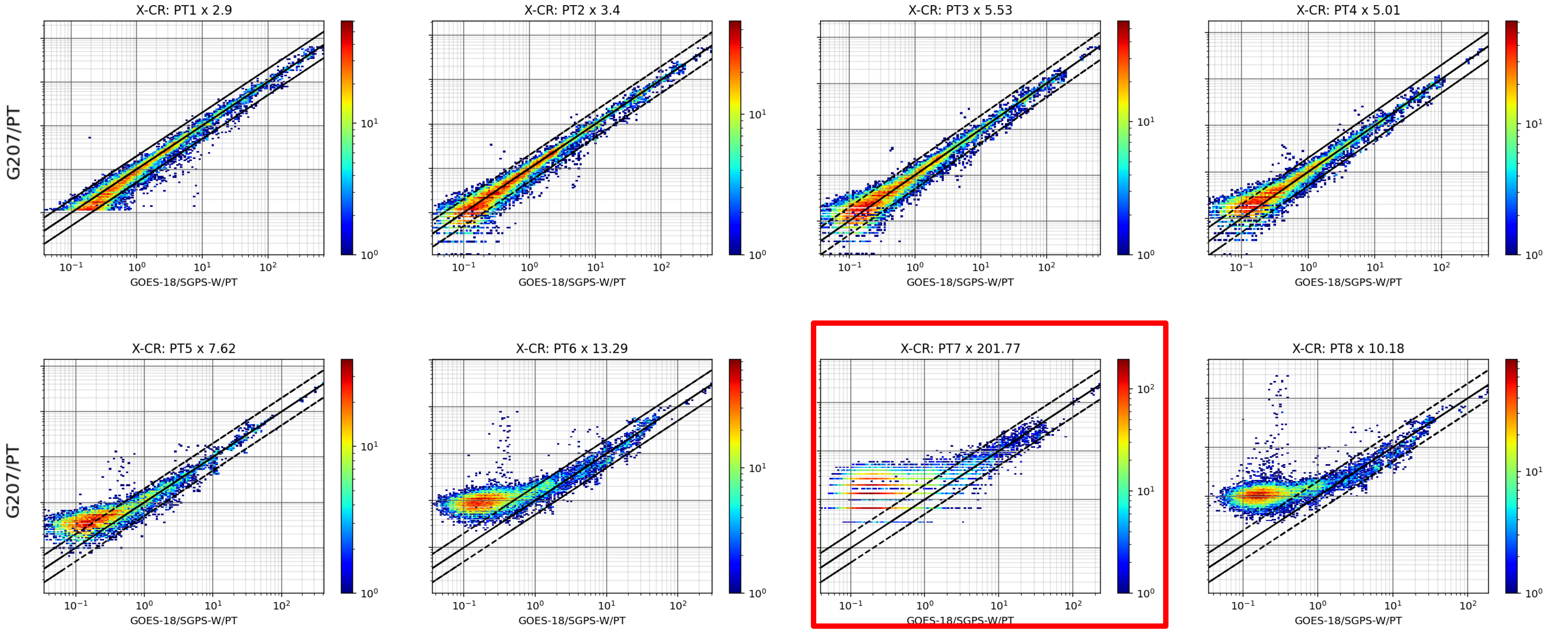
X-GSAT207/PT vs GOES-18/SGPS-WEST CRs



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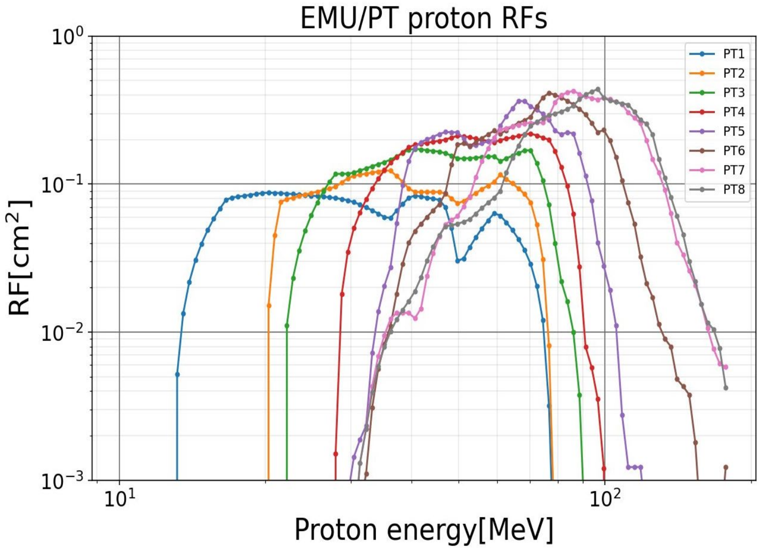
Cross-calibrated EMU/PT proton fluxes

- Use cross-calibrated count-rates
- Consider the Ellison-Ramaty function:

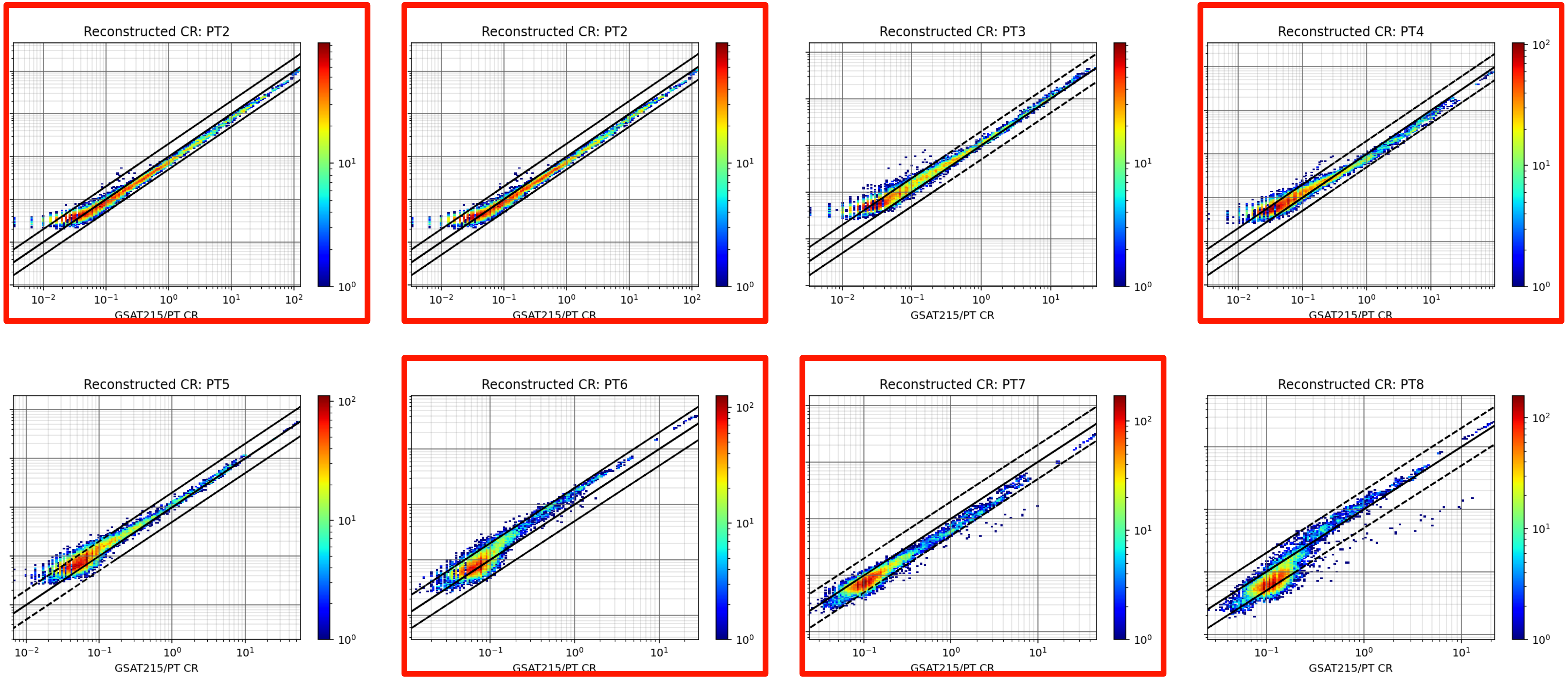
$$J(E) = J_o E^{-\gamma} e^{(-E/Er)}$$

- Seek for J_o, γ, E_r values that reconstruct optimally the (cross-calibrated) count-rates
- ~~Treat background values~~
- Evaluate data reconstruction
- Compare with "reference" fluxes



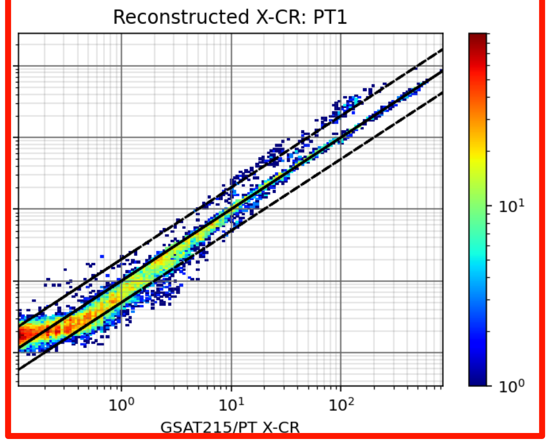
WORK IN PROGRESS

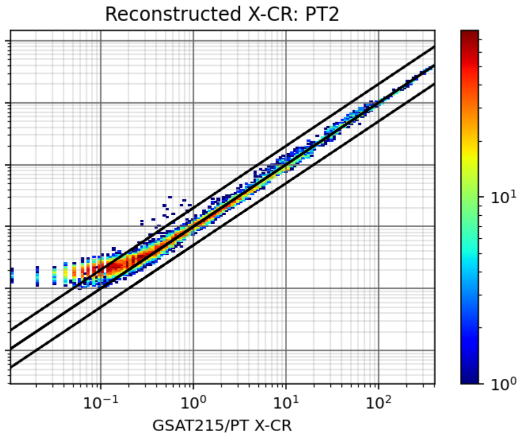
Reconstruction of GSAT215/PT raw CRs

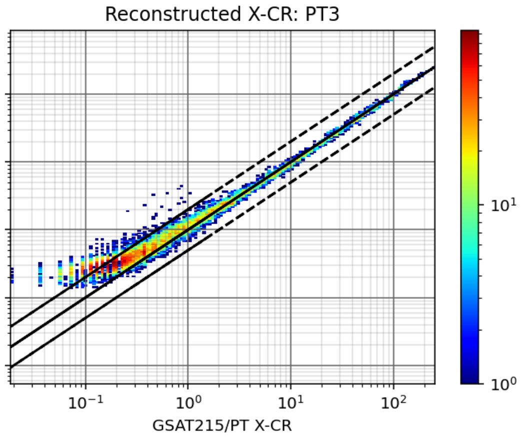


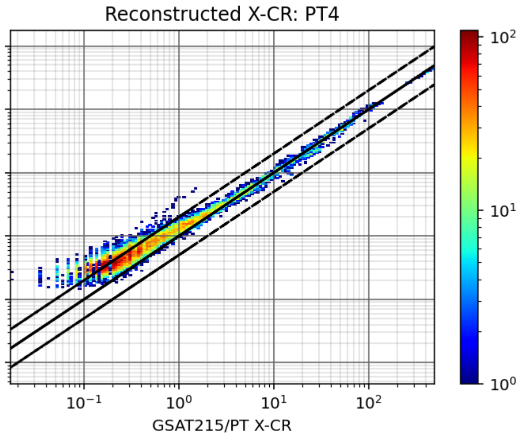
WORK IN PROGRESS

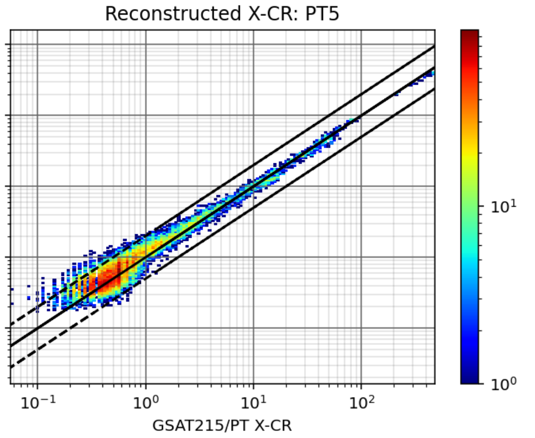
Reconstruction of GSAT215/PT X-CRs

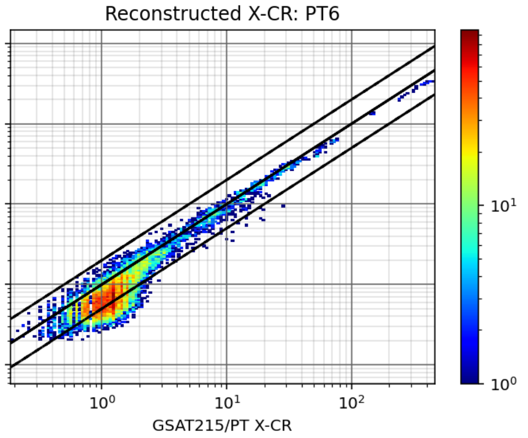


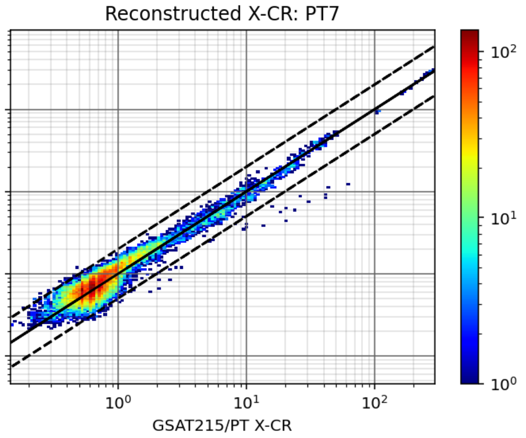


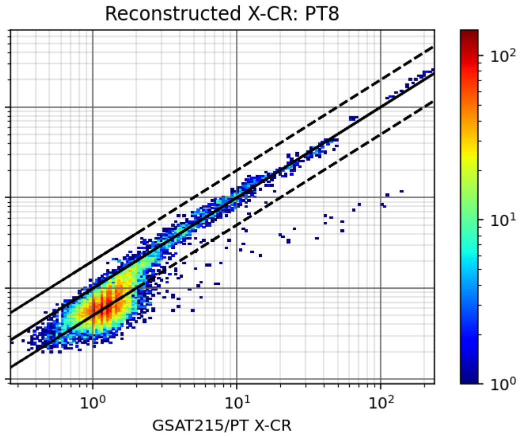






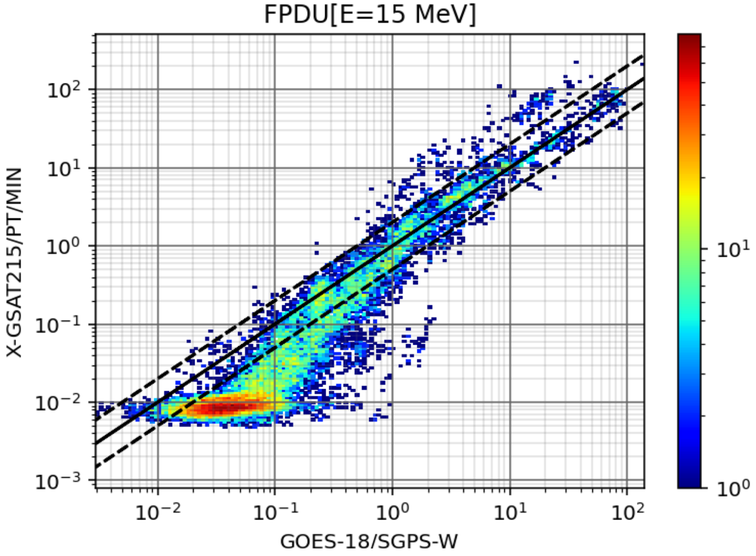






WORK IN PROGRESS

GSAT215/EMU/PT cross-calibrated fluxes



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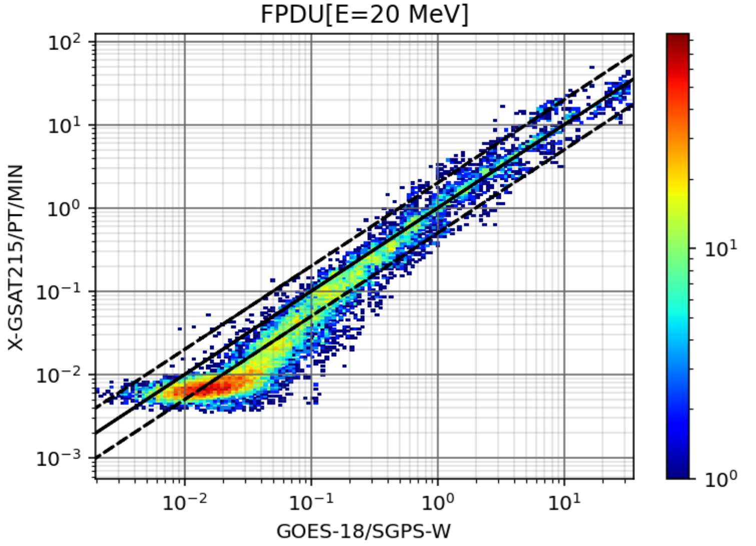

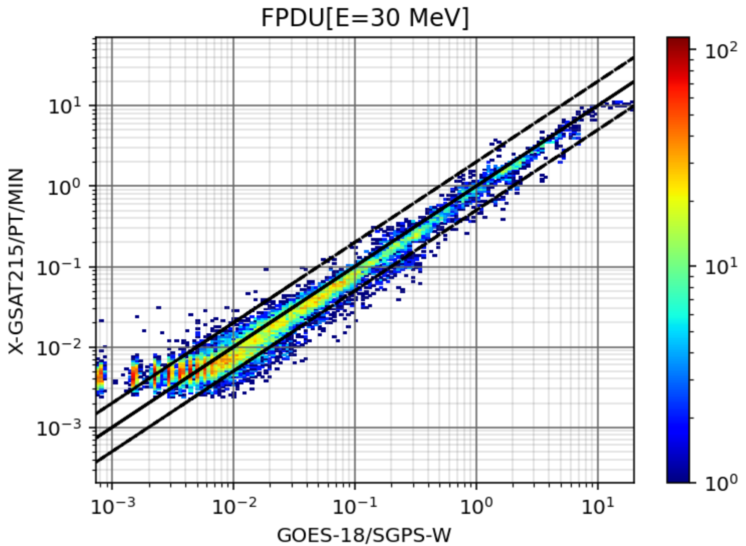

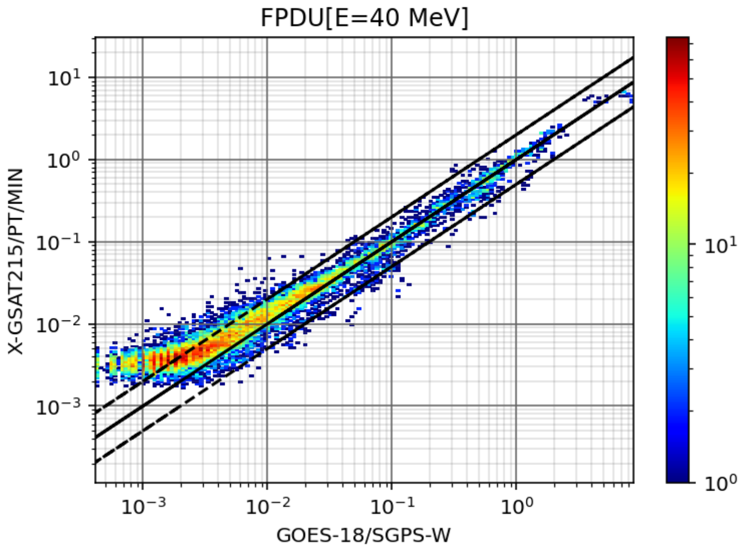

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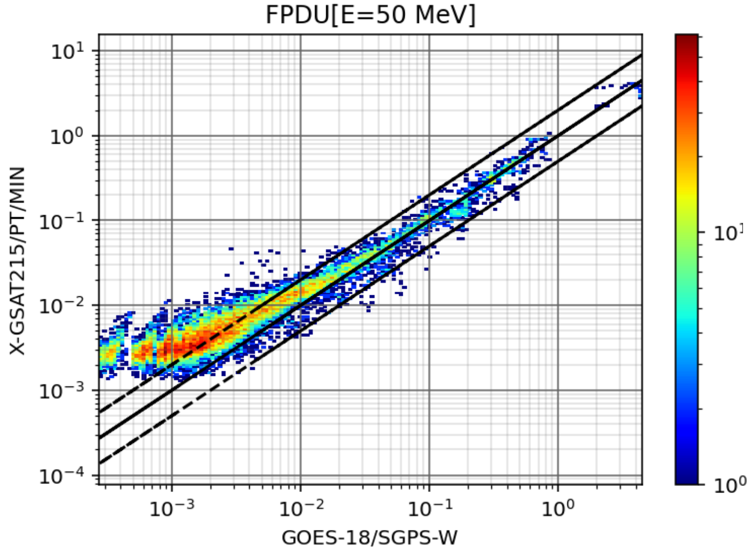
WORK IN PROGRESS

GSAT215/EMU/PT cross-calibrated fluxes



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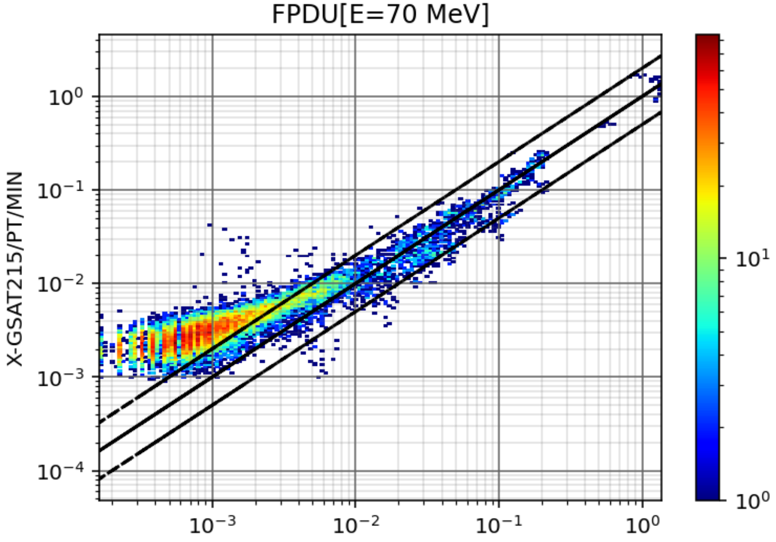

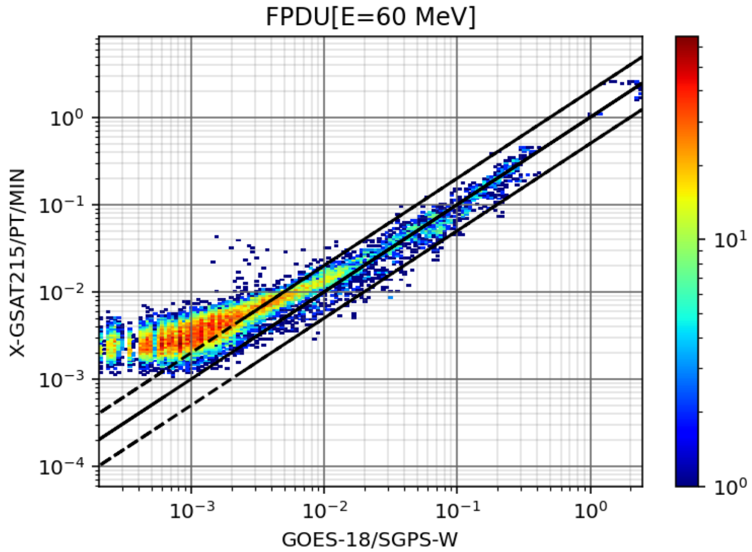

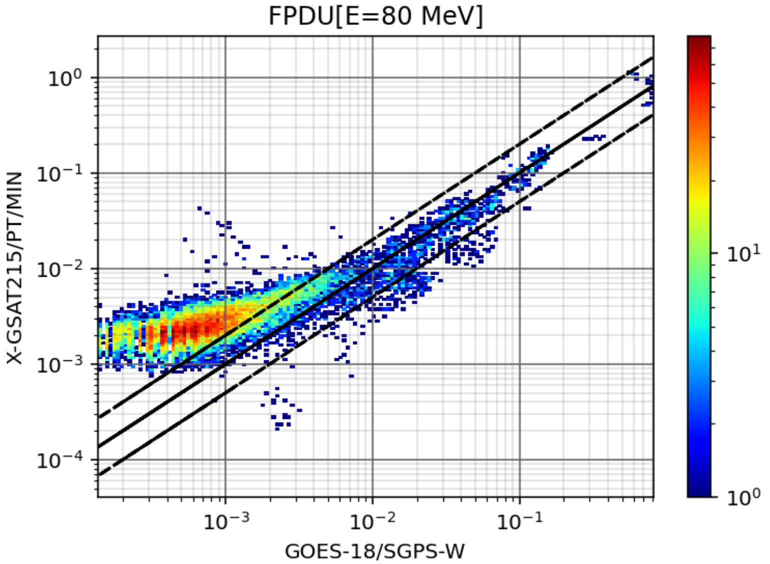

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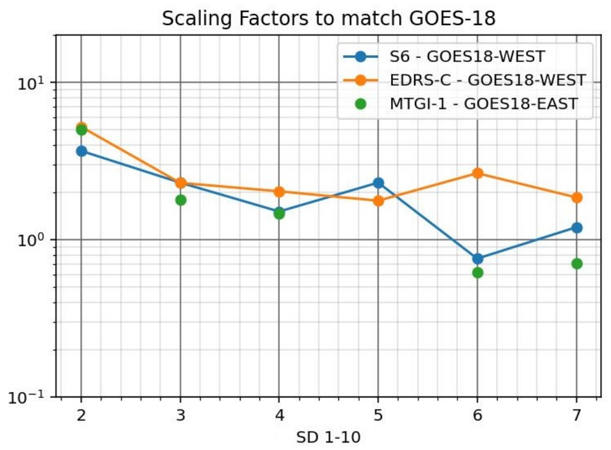
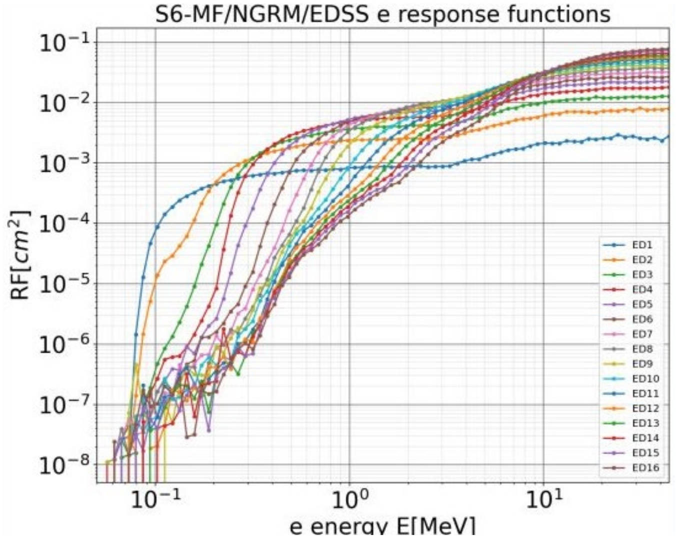


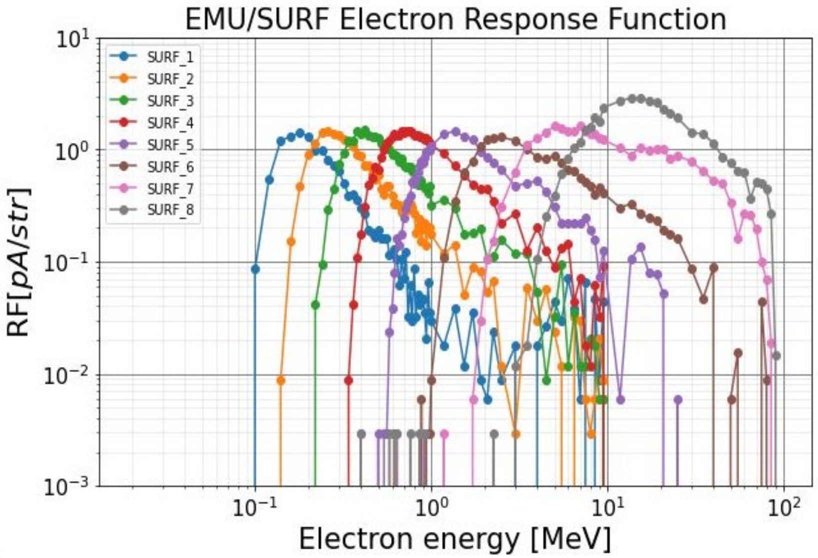
Conclusions

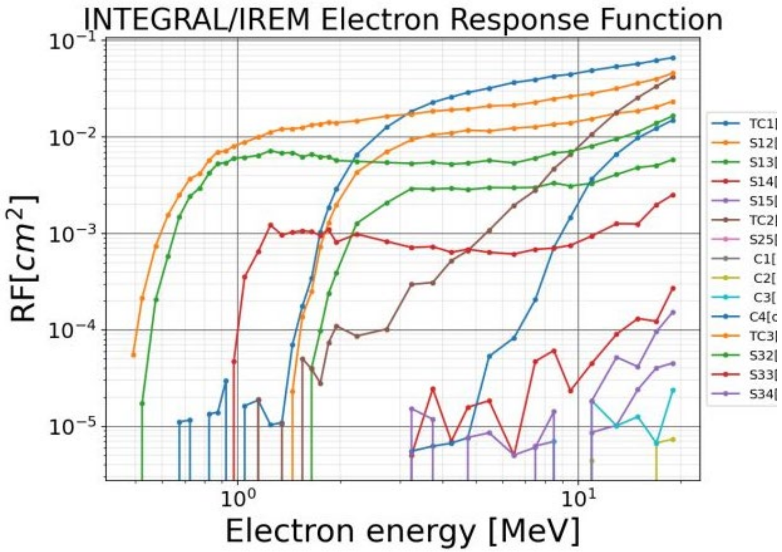
- A reference proton dataset for the current solar cycle should be identified!
- EAST-WEST effect should be considered during SPE calibrations
- The actual response of the proton sensors of NGRM and EMU units present differences with respect to "reference" datasets
    - Cross-calibrations introduce considerable adjustments for EMU proton telescopes.
- Bow-Tie analysis/multiplication factor works "sufficiently well" for NGRM, but not so well for EMU/PT proton fluxes: new approaches are needed
- Lessons from/to Himawari-8-9/SEDA proton telescopes can be useful!
- Inter-consistency among different GOES NOAA (e.g. EPS to SGPS) datasets can be verified indirectly using INTEGRAL/IREM 23+ years data and response functions.
- GSICS 2024-2025: The electron sensors of NGRM and EMU units are well-characterized
    - Cross-calibrations with selected "reference datasets" introduce small adjustments

See presentations GSICS 2023, 2024

Electron sensors/datasets

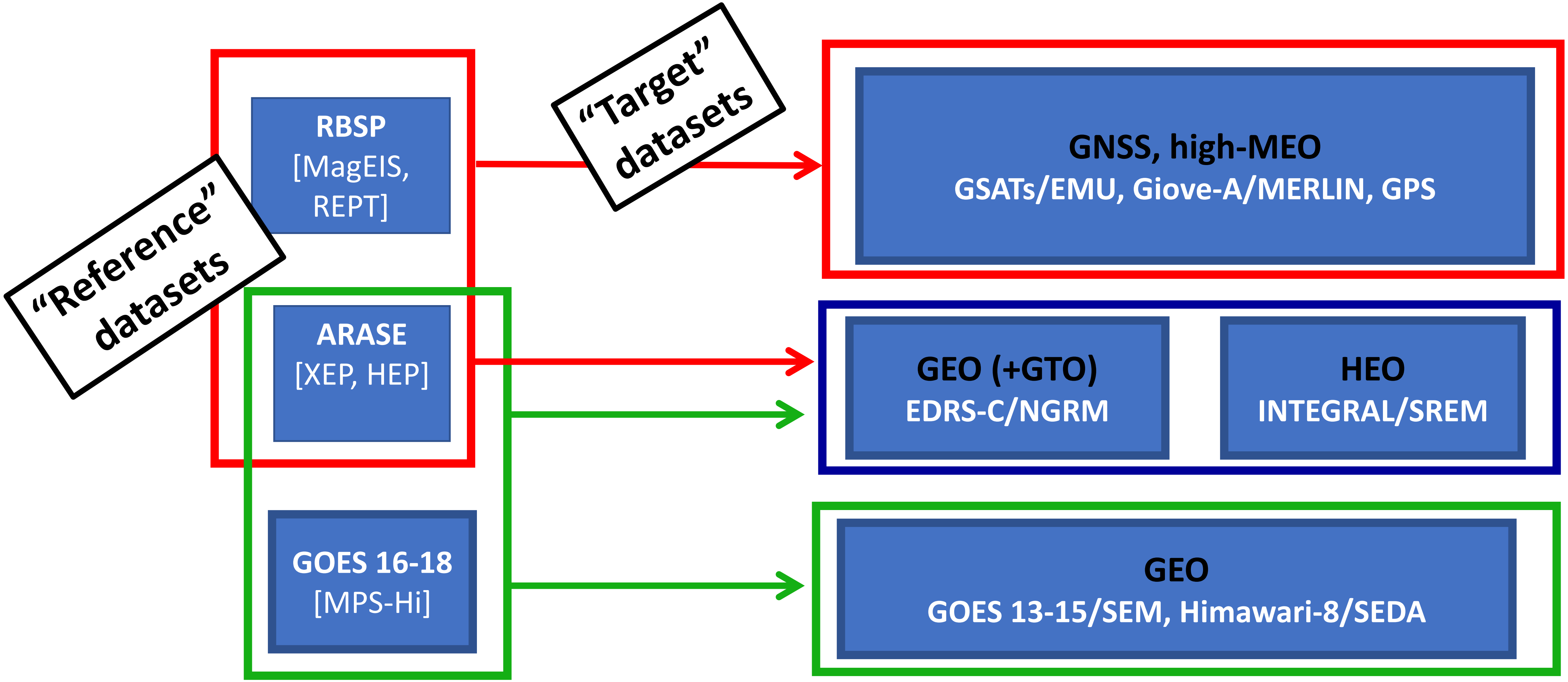






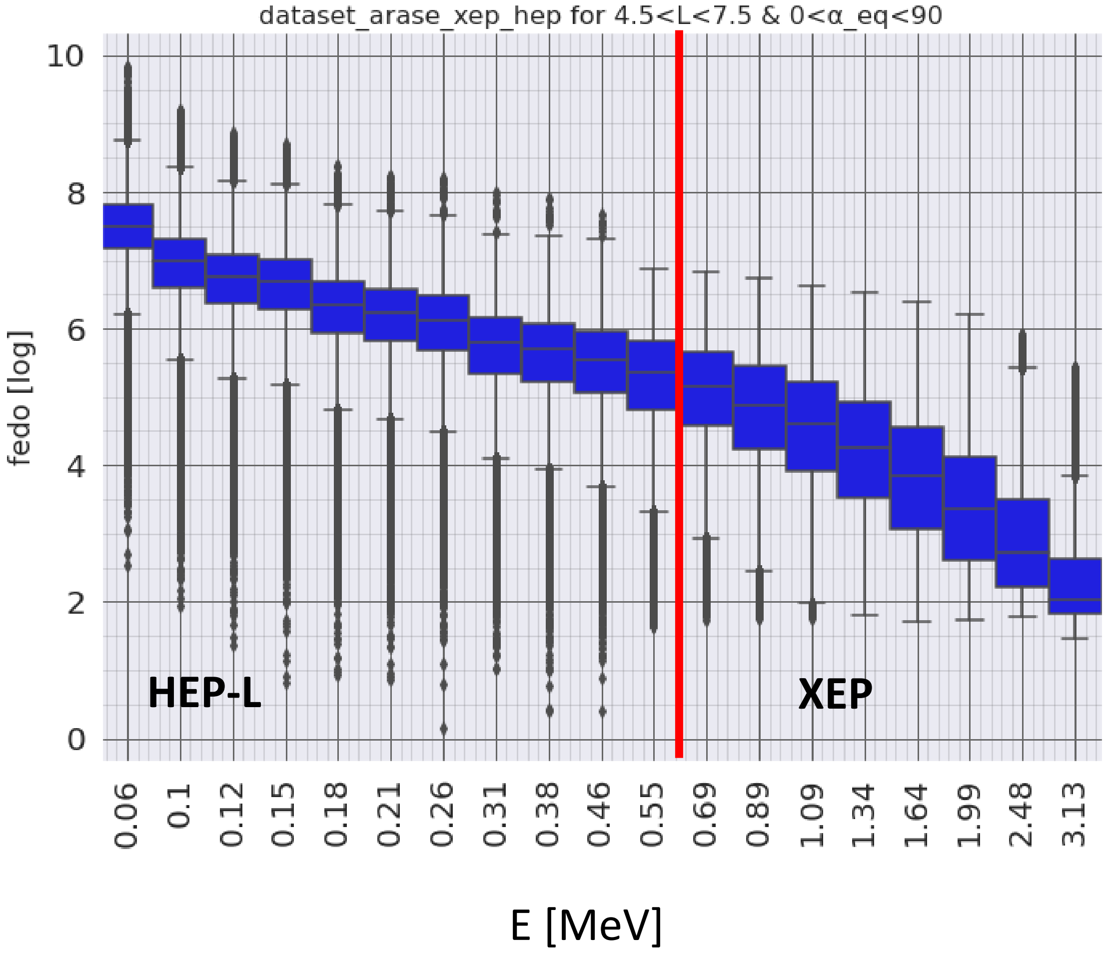
See presentations GSICS 2023, 2024

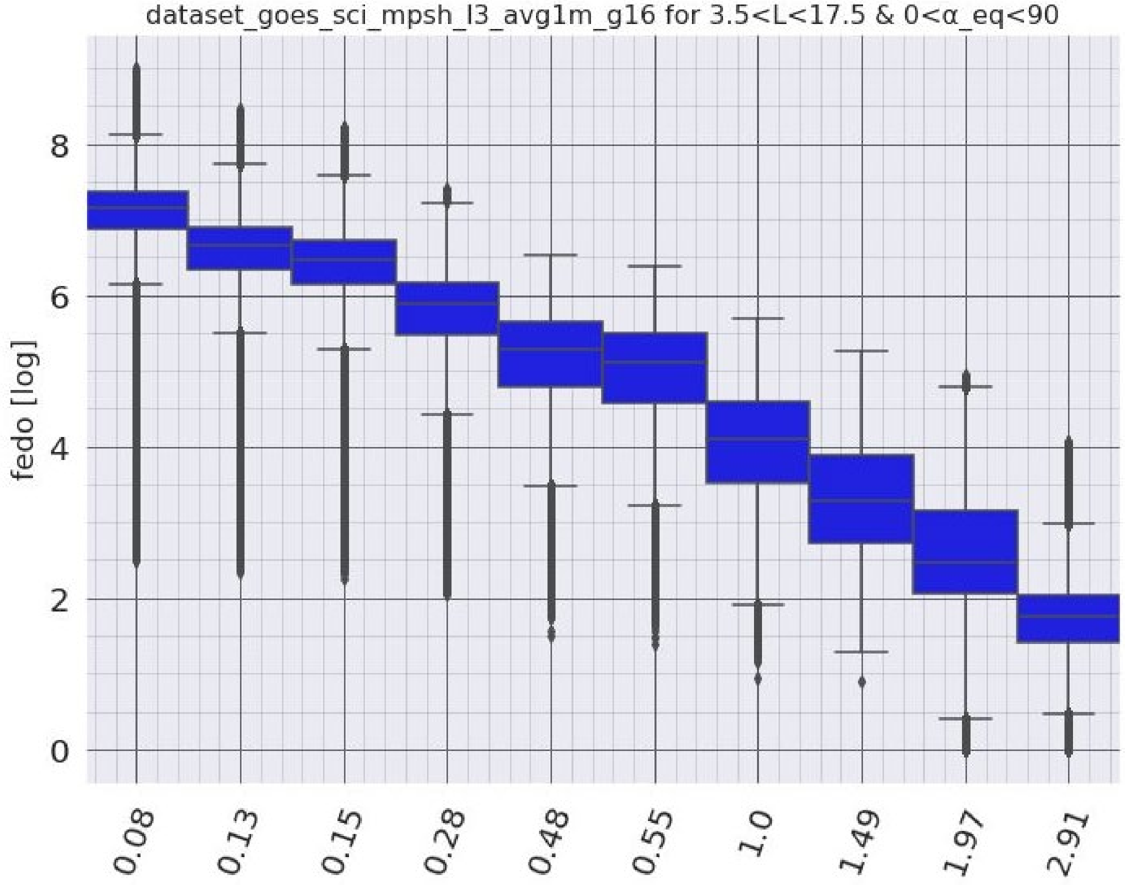
Inter-calibration of electron datasets: a roadmap



See presentations GSICS 2023, 2024

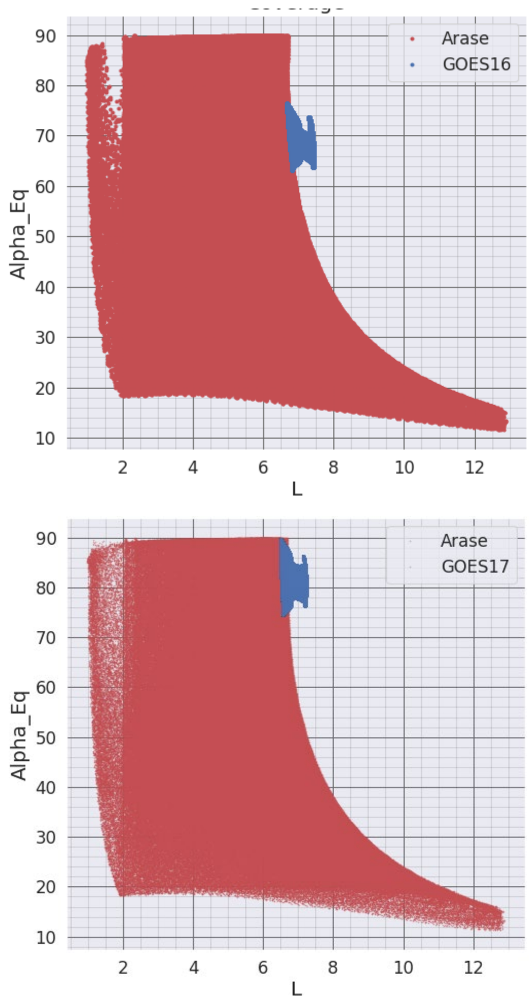
Reference datasets

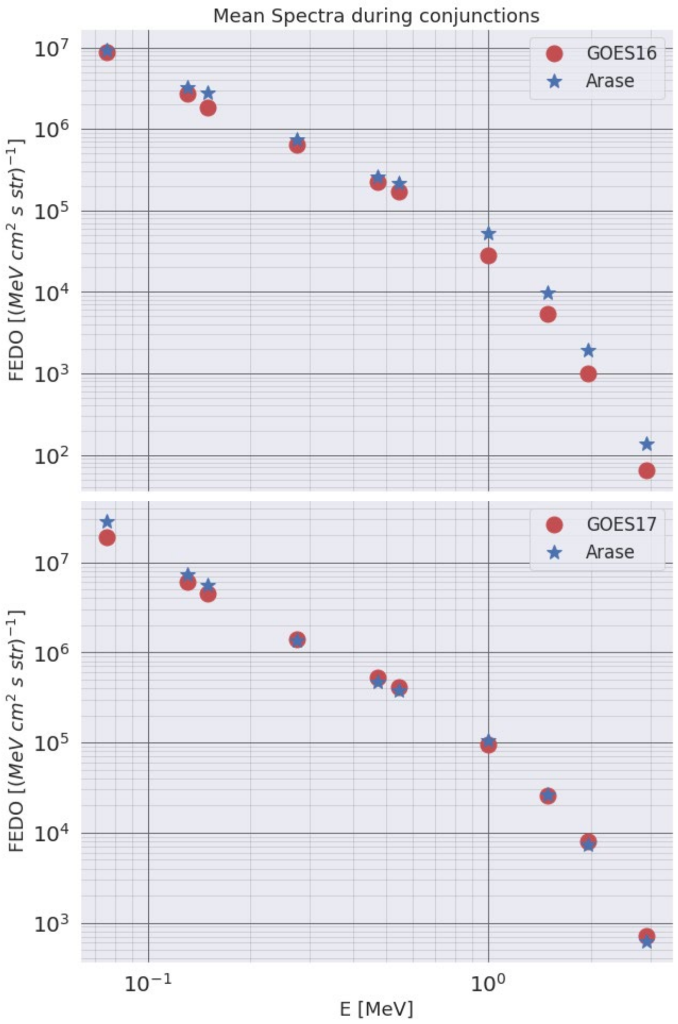


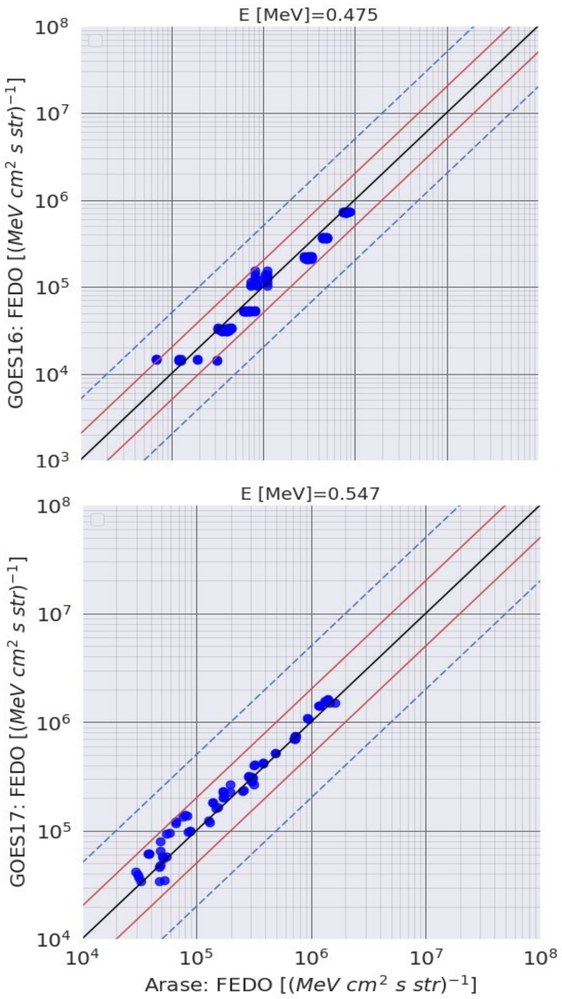


See presentations GSICS 2023, 2024

GOES 16-17/MPS-Hi vs Arase/HEP-XEP







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cad	1
cad_times	5
delta_l_max	0.2
delta_alpha_eq_max	2
delta_mlt_max	24
L_lims	[1, 10]
alpha_eq_lims	[72, 90]
mlt_lims1	[0, 24]
mlt_lims2	[0, 24]
kp_days	2
kp_lim	100

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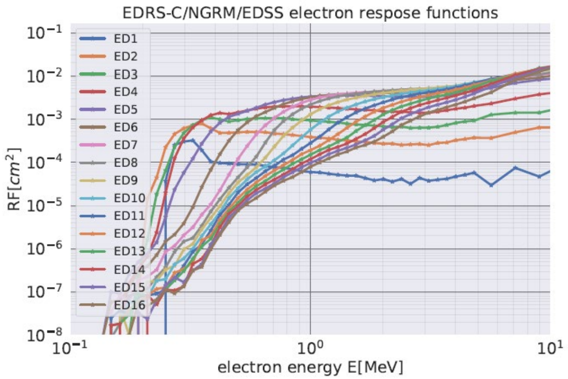
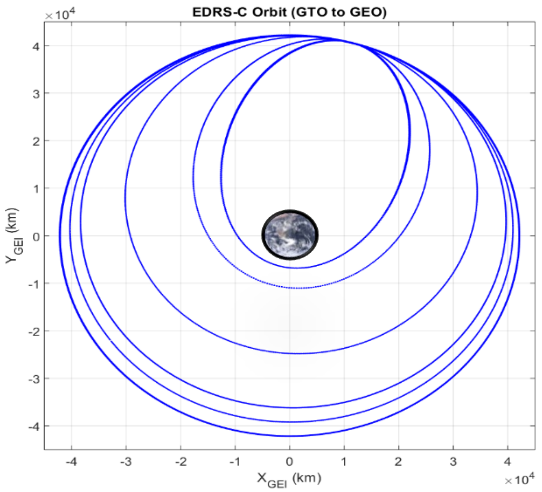
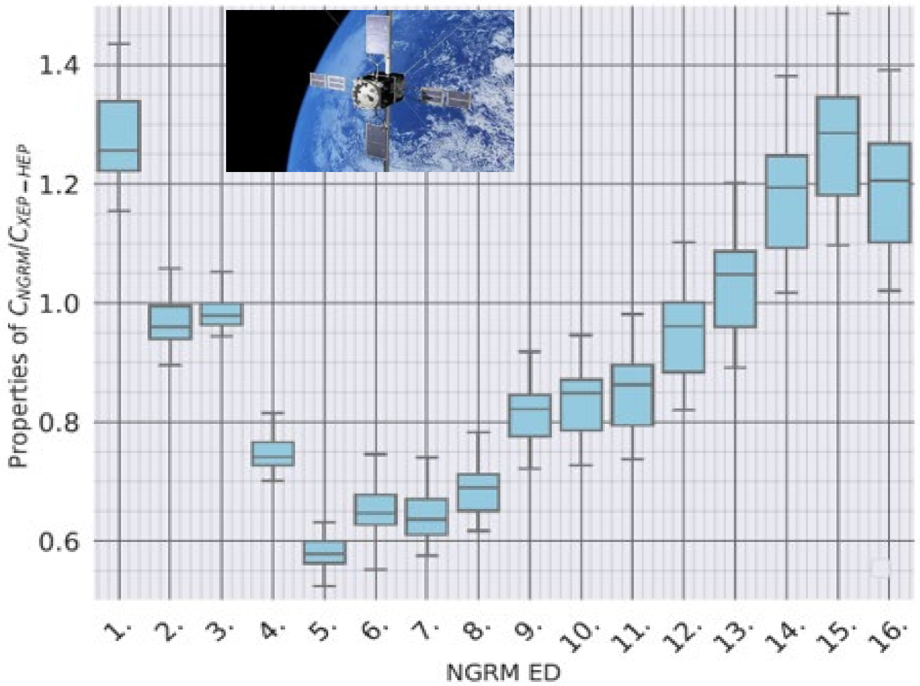
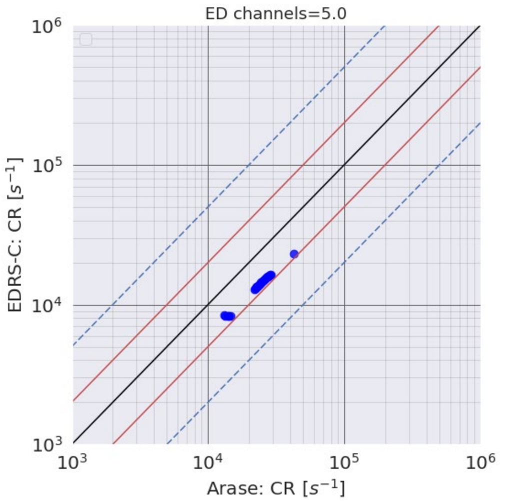
See presentations GSICS 2023, 2024

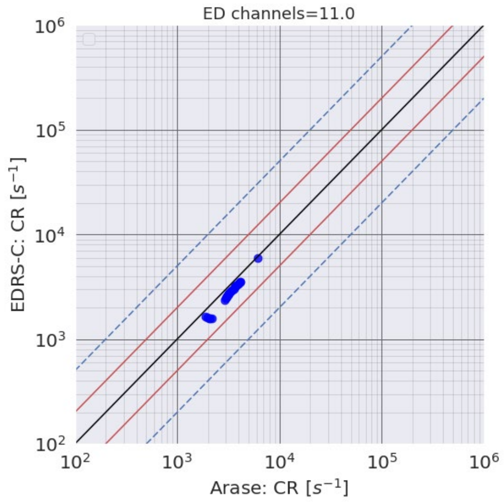
EDRS-C/NGRM Level 2 using Arase











I Sandberg et al *https://doi.org/10.1109/TNS.2022.3160108*

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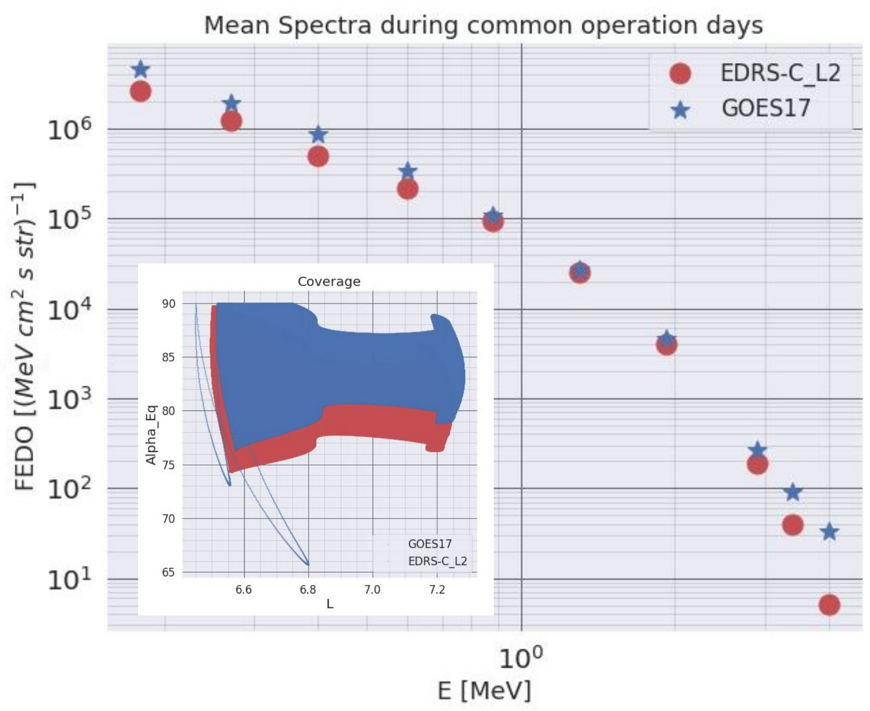
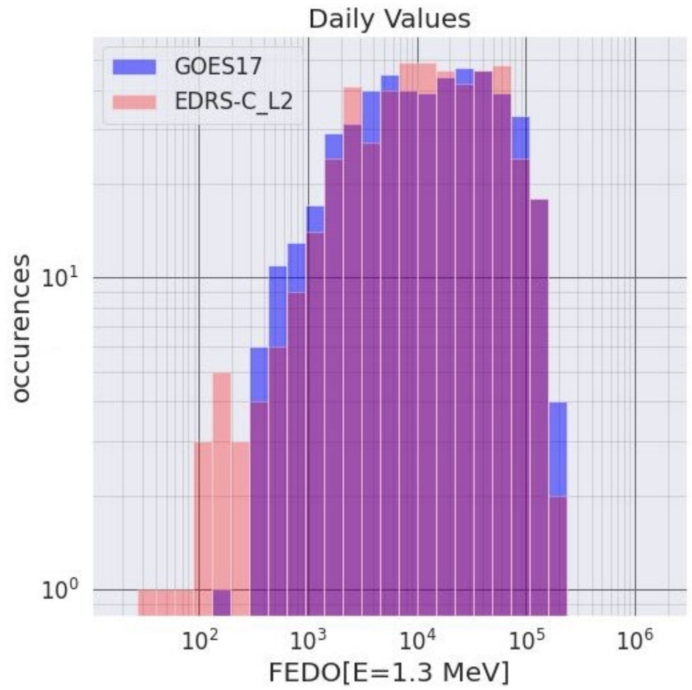
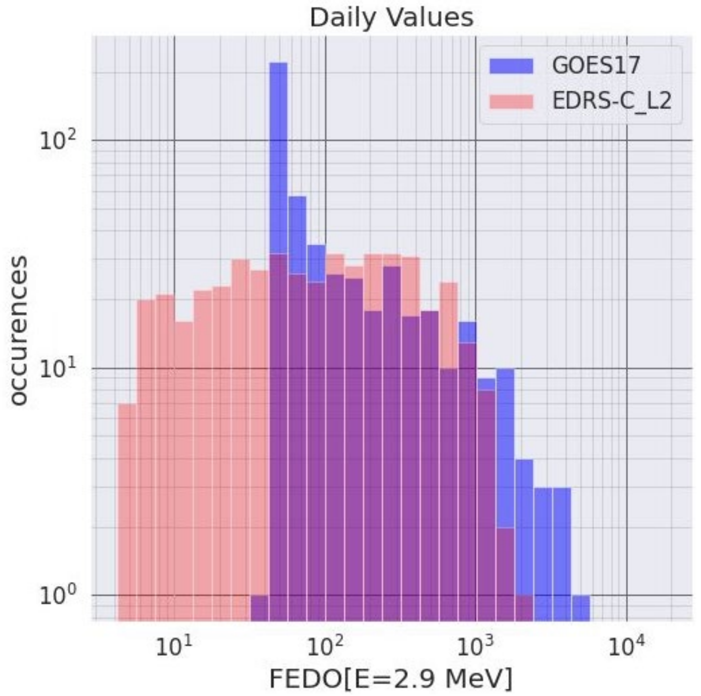
See presentations GSICS 2023, 2024

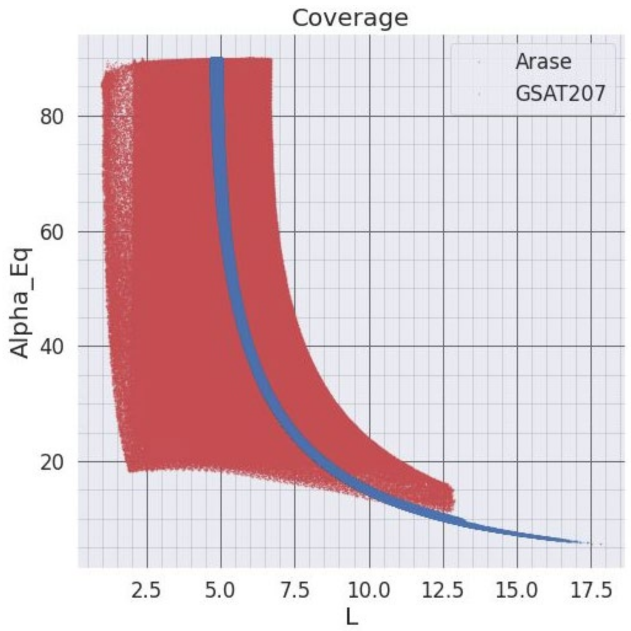
EDRS-C/NGRM L2 vs 17/MPSH

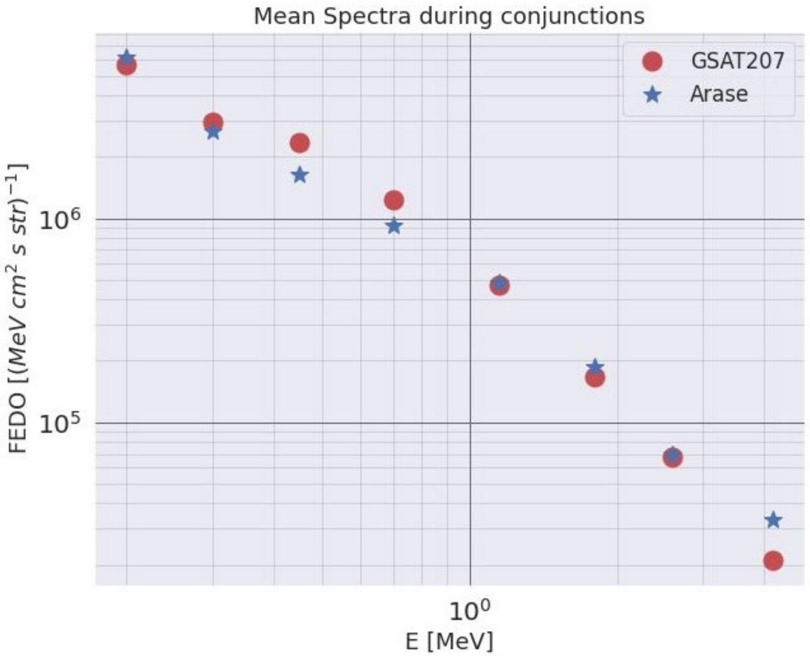


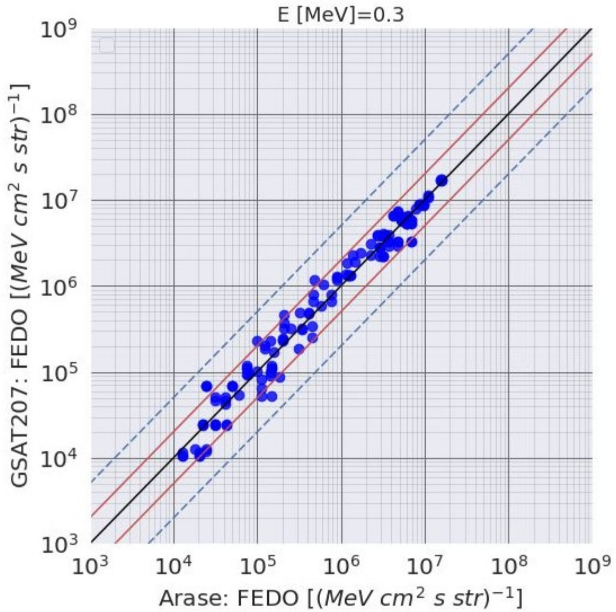




GSAT207/EMU L1 vs ARASE







type_orbit	HEO
cad	5
cad_times	3
delta_l_max	0.1
delta_alpha_eq_max	5
delta_mlt_max	24
L_lims	[4.0, 7.0]
alpha_eq_lims	[85, 90]

Inter-Calibration “System”

- **UNILIB library: IGRF model & Olson-Pfitzer 1977**
- **Conjunction conditions**
  - **HEO:**
    - **$\delta(t)$, $\delta(MLT)$, $\delta(L^*)$, $\delta(\alpha_{eq})$, $\alpha_{eq} \sim 90$**
    - **MLT = [3, 9] or [15, 21], Kp<2 for 2 days, $\alpha_{eq} \sim 90$**
  - **GEO-GEO**
    - **$\delta(t)$ or $\delta(MLT)$, $\delta(L^*)$, $\delta(\alpha_{eq})$, $\alpha_{eq} \sim 90$**
    - **long term averages**
- **Identify conjunctions: quick search algorithm**
  - **Derive measurements with:**
    - **same integration period**
    - **Identical time-stamps**

Panel on Radiation Belt Environment Modeling (PRBEM)

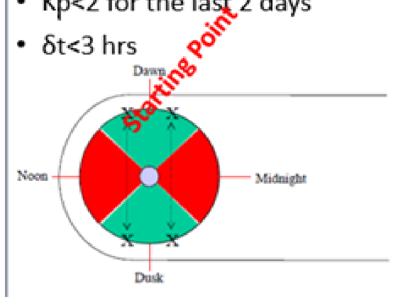
Data analysis procedure

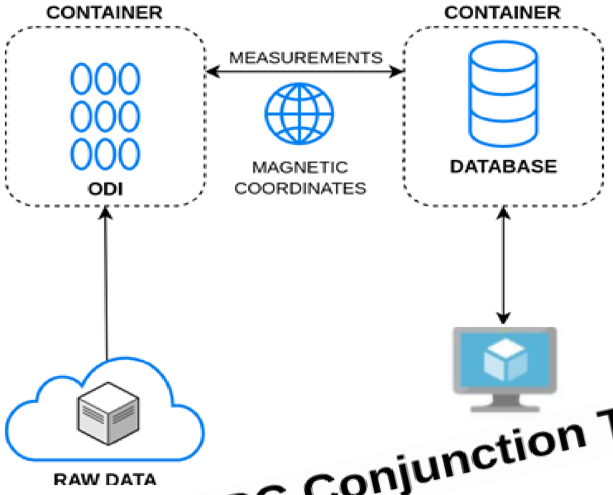
V1.2

S. Bourdarie (ONERA - France)
B. Blake (Aerospace Corporation – USA)
J.B. Cao (CSSAR – China)
R. Friedel (LANL – USA)
Y. Miyoshi (STELAB – Japan)
M. Panasyuk (MSU – Russia)
C. Underwood (U. Of Surrey – UK)

Conjunction Conditions

- $L^* < 6$ & $\Delta L^* < 0.1$
- $\delta(B/Beq) < 0.1$ and $B/Beq \sim 1$
- 4 (16) <MLT<8 (20),
- Kp<2 for the last 2 days
- $\delta t < 3$ hrs





SPARC Conjunction Tool

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Inter-Calibration “System”

- **Evaluate determined conjunctions/Update conditions**
- **On-the-fly calculation of the “reference data product”**
  - Interpolation/integration to target flux energies
  - Construction of sensor measurements (count-rates/charging currents) provided RF availability
- **Define scaling factors**
  - **R = median(J_B /J_A):** J_A and J_B denote the series of joint observations by the satellites of the reference A and the target B
  - **SF_{fit}= sf | min(MSE) (lin/log)**
  - **Rescale: J'_B= J_B /R,** or **by J'_B= J_B /SF_{fit}**
  - **Dlnj=$[(1/n)(\Sigma (\ln(J'_B/ J_A))^2)]^{0.5}$** (random error of series)