Intercalibration of electron flux measurements; on-going results and lessons-learnt

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SPACE APPLICATIONS & RESEARCH CONSULTANCY

SPARC, GREECE

Acknowledgments

DATASETS/DISCUSSIONS

- 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)
- K. Ryden, University of Surrey, UK (Giove-A/SURF, GSAT/EMU)
- D. Baker, S. Claudepierre, A. Boyd, USA, (RBSP/ECT datasets)
- H. Evans, P. Jiggens, M. Heil, ESA Technical officers

SPARC Team

- I. Sandberg
- C. Papadimitriou
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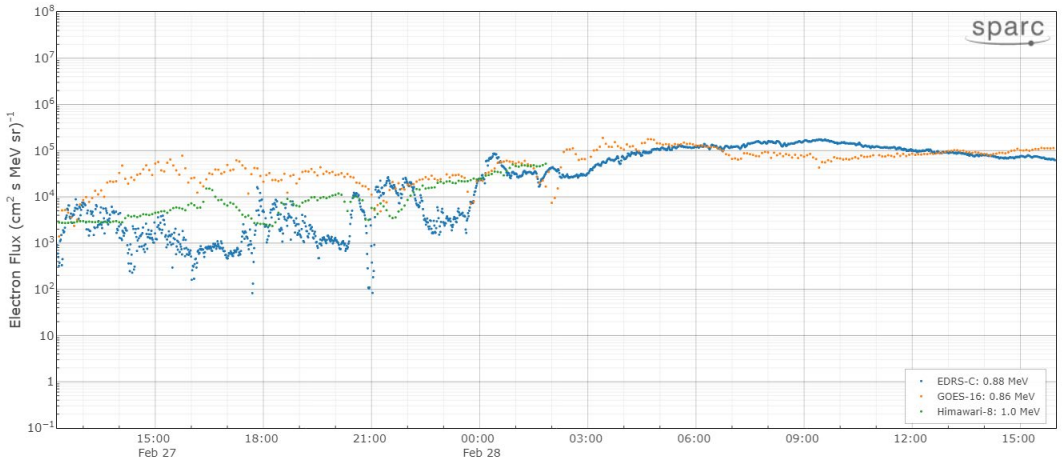
- Z. Iqbal

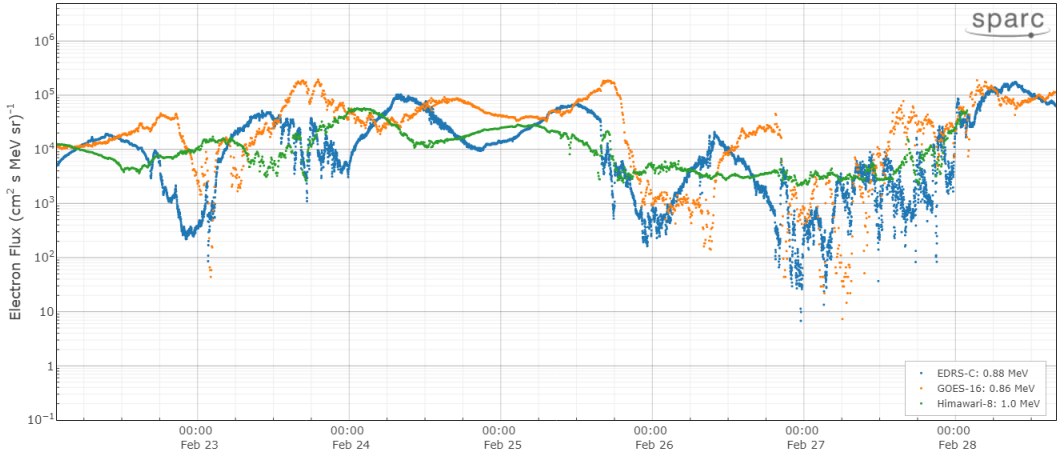
FUNDING/SUPPORT

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

Outline

- Motivation
- List of datasets
- Roadmap
- Reference datasets
- Intercalibration “system”
- Conjunction algorithm
- Examples - results
- Lessons learnt - discussion





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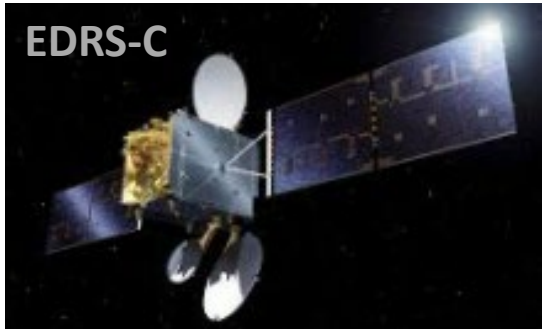
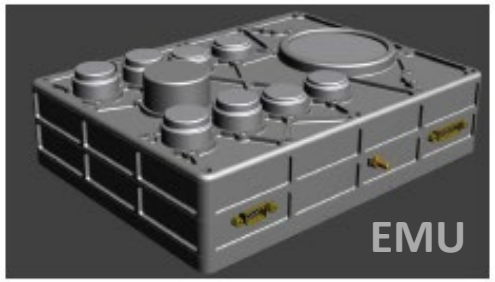
Motivation: calibrate ESA monitors

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





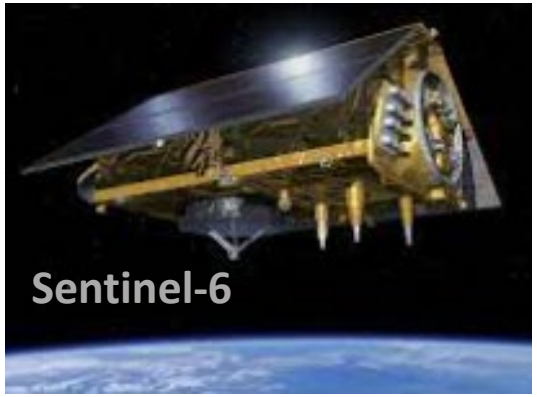
- **GEO EDRS-C**
- **LEO Sentinel-6**
- **GEO MTG1**

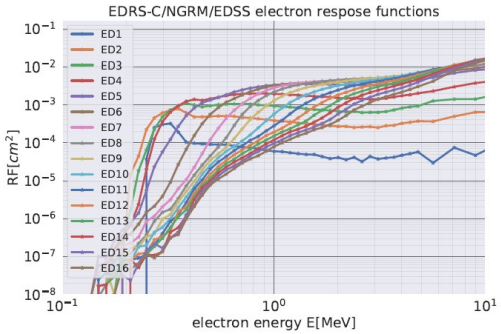
… + more to come

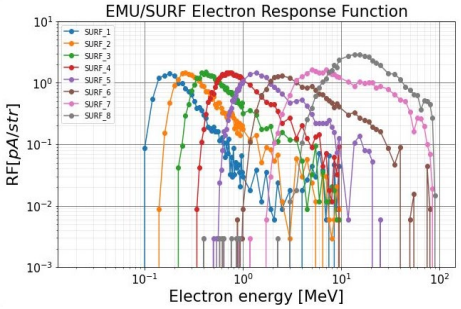
- **GNSS GSAT-0207**
- **GNSS GSAT-0215**
- **GNSS Giove-A (SURF)**

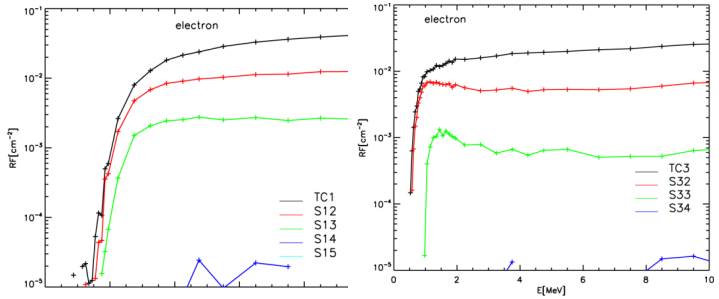
- **HEO INTEGRAL**
- **LEO PROBA-1**
- **GNSS Giove-B**

…. + more









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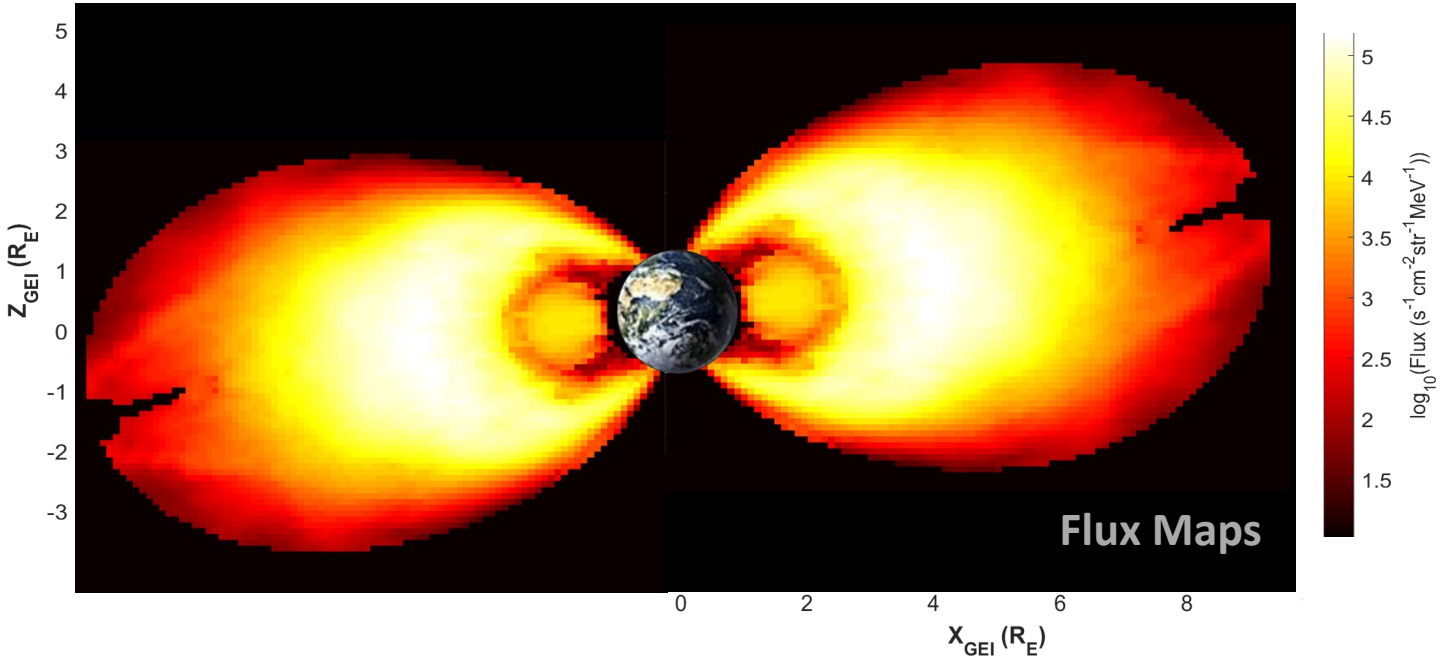
Motivation: harmonize electron flux datasets

- Create a database with historical clean and inter-calibrated electron flux datasets for the development, update, validation of radiation belt specification models.



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Datasets of interest

Mission/Instrument	Orbit	Perigee × Apogee (km)	Incl.(deg)	Electrons (MeV)	Mission duration/ Data availability
Arase/HEP Low	HEO	460 × 32,110	32	0.06–1.60	12/2016-today
Arase/HEP High	HEO	460 × 32,110	32	0.58–2.12	12/2016-today
Arase/XEP	HEO	460 × 32,110	32	0.55–3.13	12/2016-today
EDRS-C/NGRM	GEO	31 East		> 0.1 MeV	08/2019-today
Galileo/EMU	GNSS	23,222	56	0.1-10	10/2011-today
Giove-A/ MERLIN/SURF	MEO	23,260	56	0.8, 1.10, 1.50	2005-2021
Giove-B/SREM	MEO	23,260	56	> 0.5	04/2008-07/2012
GOES-13-15/ SEM/EPEAD	GEO	35,786	~ 0.2	>0.8, > 2.0, > 4.0	05/2010-2017/12 01/2010-2022/03 09/2010-2020/03
GOES-16-17/ MPS-HI	GEO	35,786	0.04 (16), 0.0 (17)	0.07-3 MeV in 10 diff channels	11/2016-today (16), 12/2017-today (17)
HIMAWARI-8/ SEDA	GEO	140.7 E		0.2,0.3,0.45,0.65, 1.0,1.5,2.0,4.5	10/2014-today
INTEGRAL/IREM	HEO	9,050 × 153,657	52.2	> 0.5	10/2002-today
PROBA-1/SREM	LEO	560 × 672	97.7	> 0.5 (D3), > 1.5 (D1,2)	10/2001-today
RBSP/MagEIS	GTO	618 × 30,500	10.2	0.02-4.8	08/2012-07/2019 (B), 08/2012-10/2019 (A)
RBSP/REPT	GTO	618 × 30,500	10.2	1.6 - 18.9	08/2012-07/2019 (B), 08/2012-10/2019 (A)

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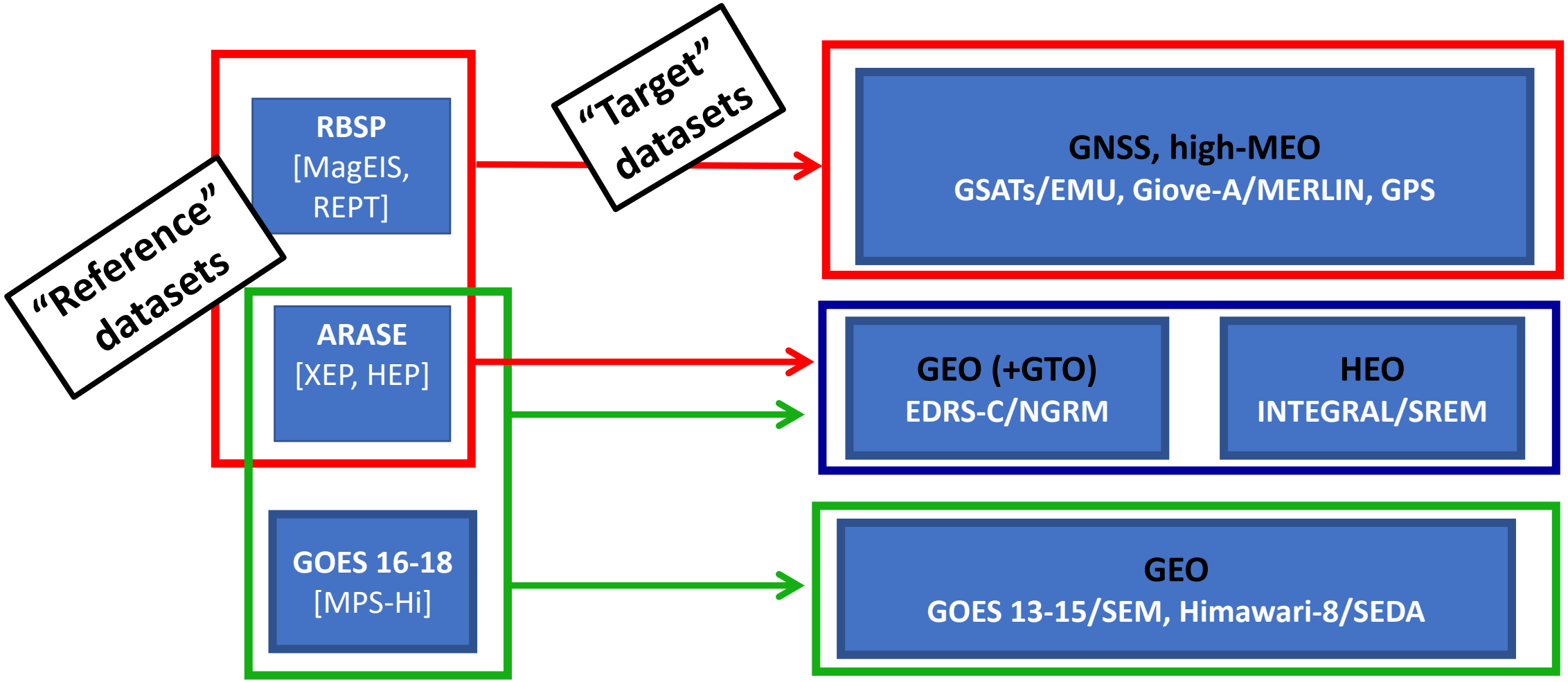
Inter-calibration of electron datasets: a roadmap



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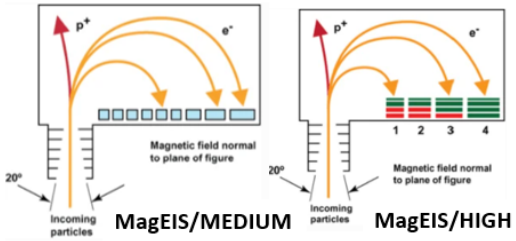
Create reference datasets: RBSP/ECT

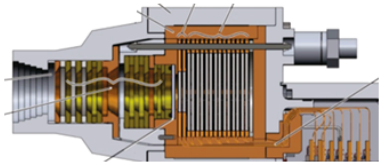
MagEIS & REPT: Part of ECT suite



MagEIS/MEDIUM MagEIS/HIGH

Level-2 Rel-4 spin averaged background corrected

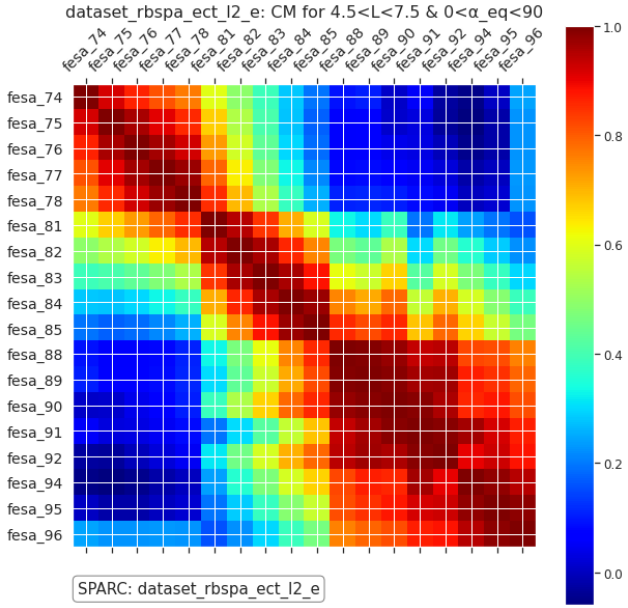
E=0.176 - 3.9 MeV

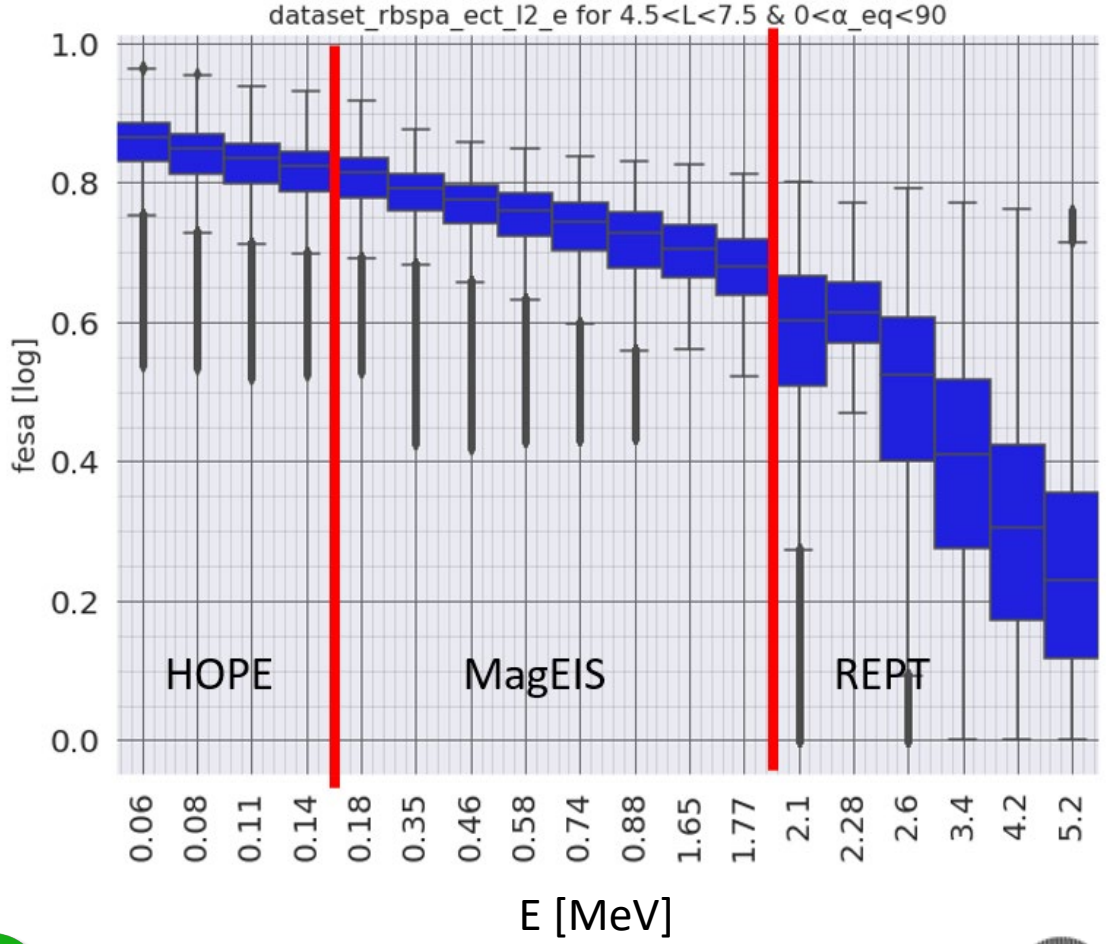


REPT

Level-2 Release 3

E=1.9 - 9.9 MeV





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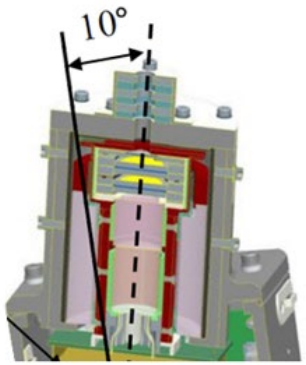
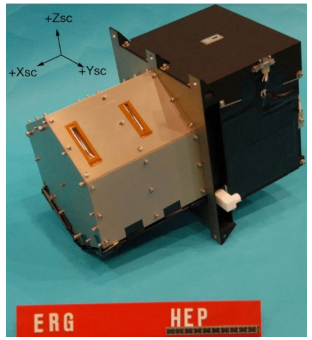
Create reference datasets: Arase/HEP-XEP



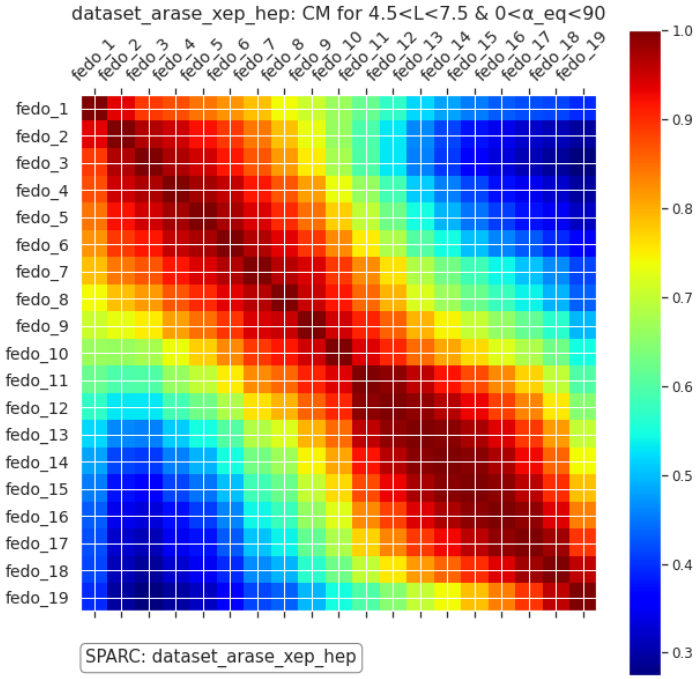
XEP

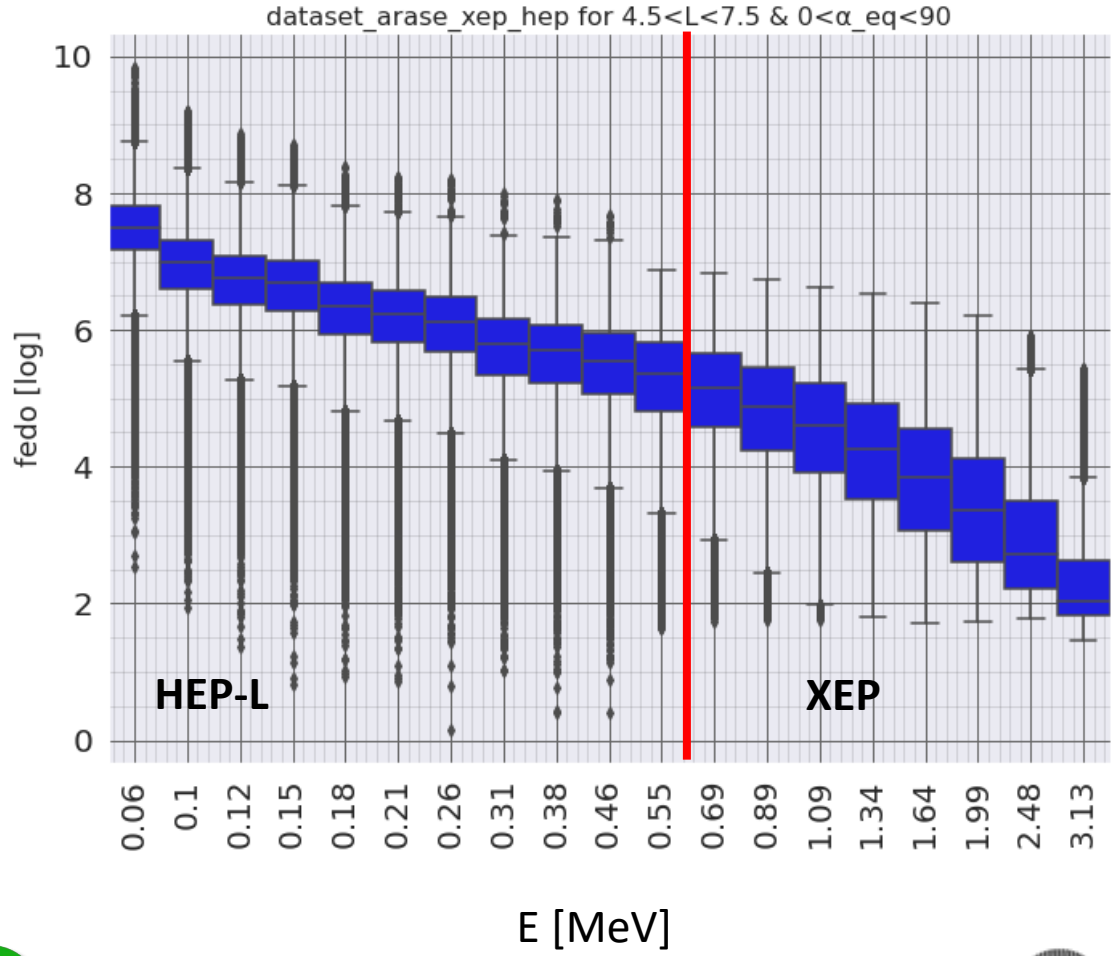
Level-2 Version 1

E=0.55-3.13 MeV



E=0.07-1 MeV





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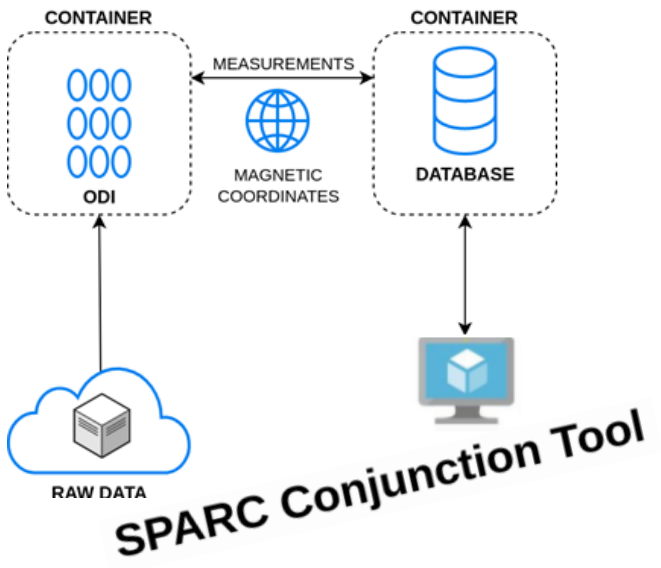
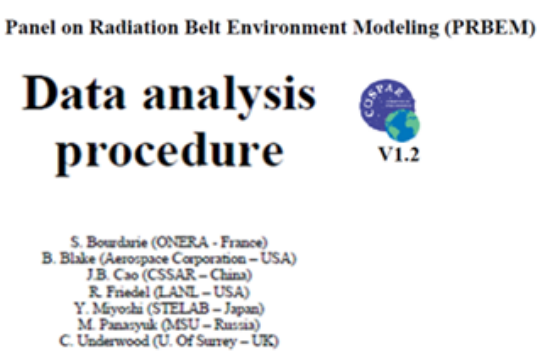
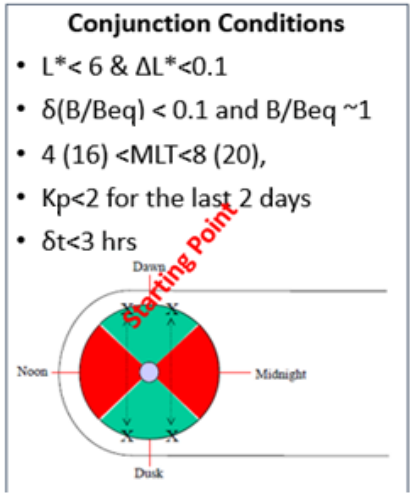
Inter-Calibration "System"

- **Datasets retrieved from Open Data Interface databases**
  - **mySQL queries to ODI**
  - **use of Python Pandas data framework**
- **Conjunction conditions**
  - **non GEO-GEO:**
    - **$\delta(t)$, $\delta(MLT)$, $\delta(L^*)$, $\delta(\alpha_{eq})$, $\alpha_{eq} \sim 90$**
    - **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)**
  - **Same integration period**
  - **Identical time-stamps**







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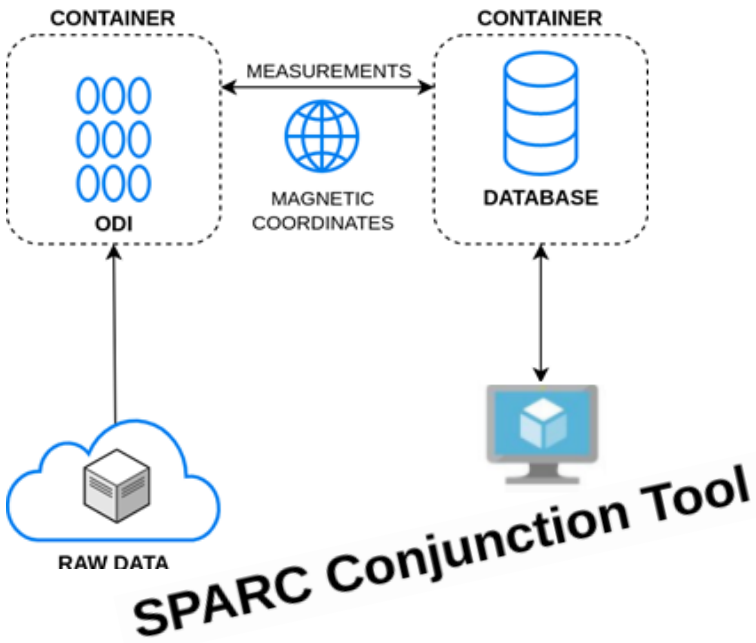
Inter-Calibration "System"

- **Evaluate determined conjunctions/Update conditions**
- **On-the-fly calculation of the "reference data product"**
  - Interpolation to target differential (FEDO) flux energies
  - Integration to target integral (FEIO) flux energies
  - Construction of sensor measurements (count-rates/charging currents) provided RF availability
- **Define/drive 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)



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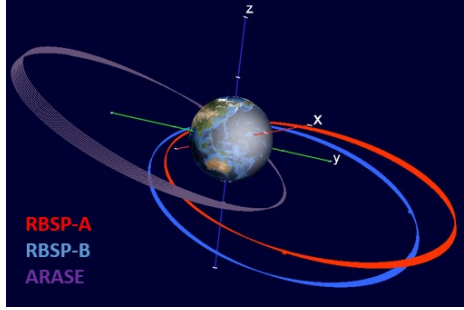
RBSP-B vs Arase/HEP-XEP



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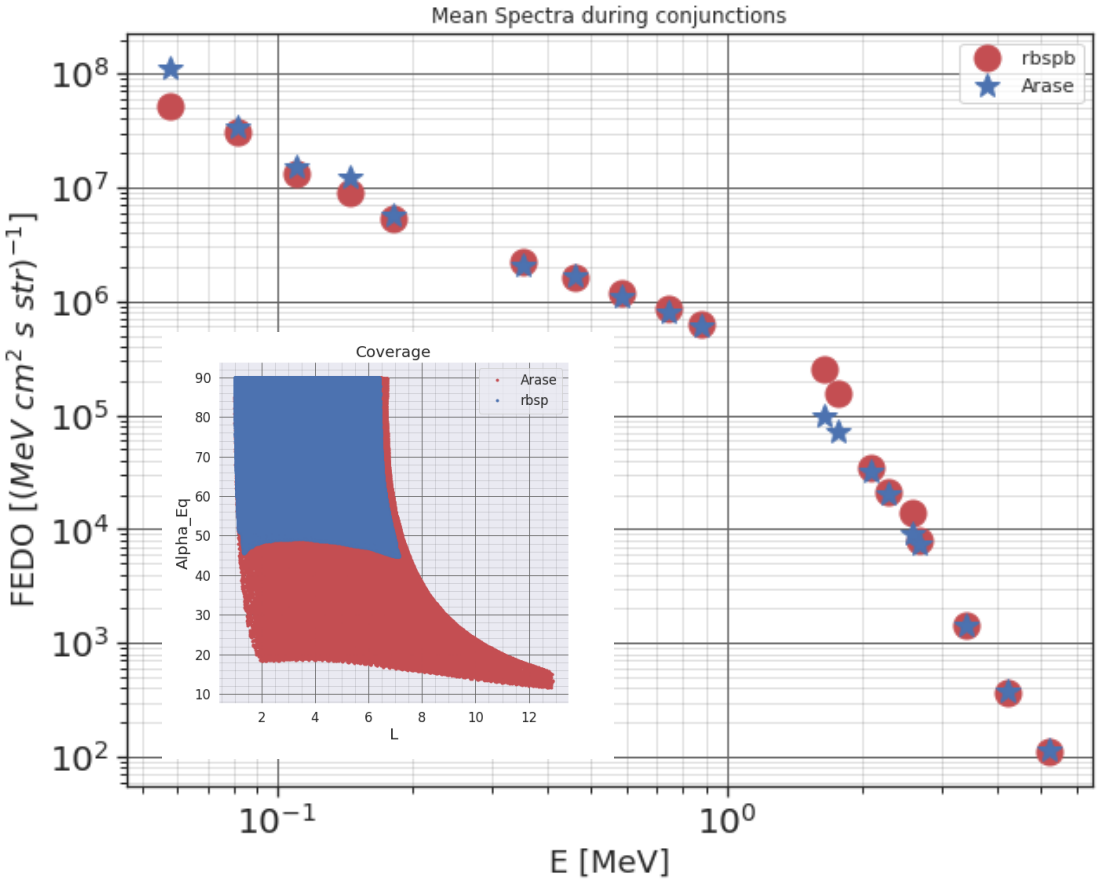
cad_times	0
delta_l_max	0.05
delta_alpha_eq_max	1
delta_mlt_max	24
L_lims	[4.0, 6.0]
alpha_eq_lims	[85, 90]
mlt_lims1	[0, 24]
mlt_lims2	[0, 24]
kp_days	2
kp_lim	100



ect[hep_xep]	E	SF_fit	SF_fit_log	mu	R	dlnj	CNTS
fesa_1_B	0.058	0.599829	0.923694	0.392704	0.328544	1.418379	27
fesa_2_B	0.082	0.965598	0.962903	0.713328	0.577144	0.553373	27
fesa_3_B	0.110	0.80194	0.989525	0.922074	0.814947	0.193329	27
fesa_4_B	0.145	0.650743	0.981556	0.794411	0.726958	0.127789	27
fesa_5_B	0.182	0.860691	0.992316	0.908359	0.867169	0.104113	27
fesa_6_B	0.354	1.04194	1.00379	1.173986	1.185106	0.6142	27
fesa_7_B	0.460	0.953979	0.994452	1.034654	0.987849	0.329118	27
fesa_8_B	0.584	1.08667	0.999036	1.067658	1.09551	0.557346	27
fesa_9_B	0.741	1.07894	0.99768	1.032436	1.100008	0.670528	27
fesa_10_B	0.879	1.032715	0.988472	0.891927	0.901005	0.311174	27
fesa_11_B	1.650	1.615847	1.035541	1.554046	1.682471	0.428757	17
fesa_12_B	1.768	1.380387	1.02375	1.335408	1.447035	0.416817	17
fesa_13_B	2.100	1.063129	0.995677	0.95006	0.961402	0.294403	27
fesa_14_B	2.280	0.600024	0.951285	0.623936	0.694165	0.53937	16
fesa_15_B	2.600	0.733505	0.974457	0.801003	0.901151	0.561999	14
fesa_16_B	3.400	0.856156	0.830374	0.634362	0.793977	7.224162	27
fesa_17_B	4.200	0.459164	0.897425	0.583154	0.754788	1.440959	15
fesa_18_B	5.200	0.324209	0.865256	0.555408	0.582012	0.210627	10

Sandberg et al, https://doi.org/10.1029/2020SW002692

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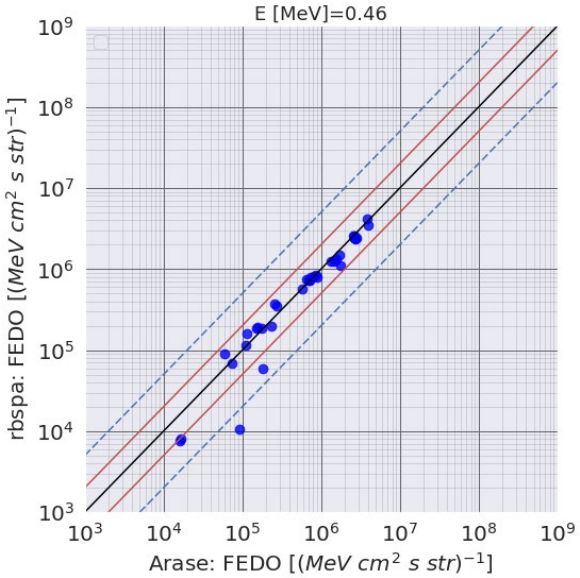
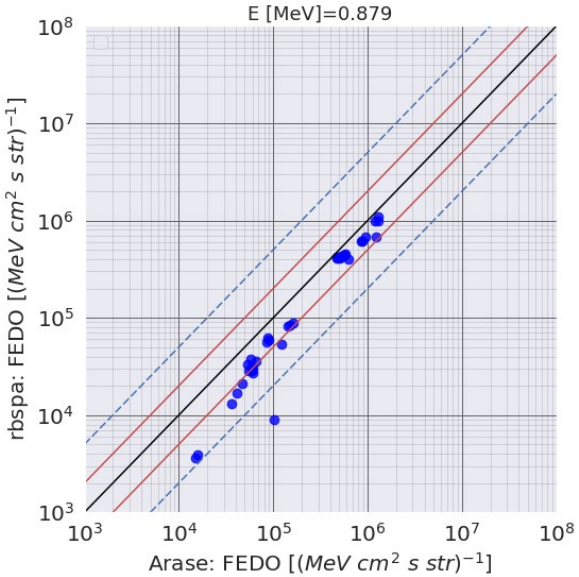
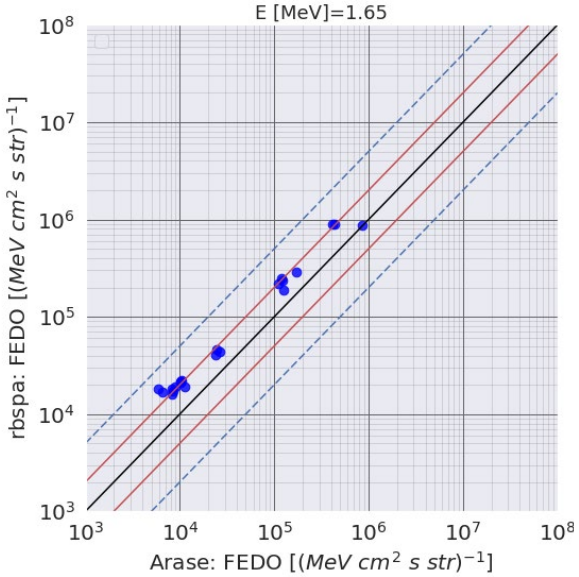
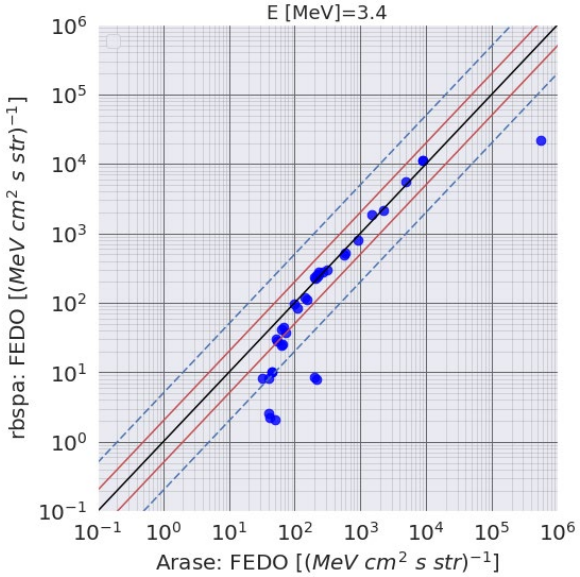
RBSP-B vs Arase/HEP-XEP









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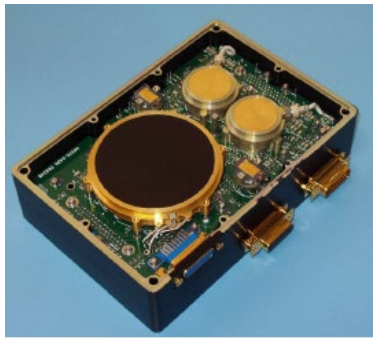
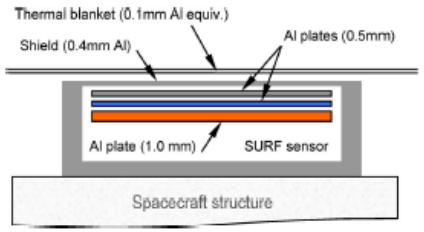
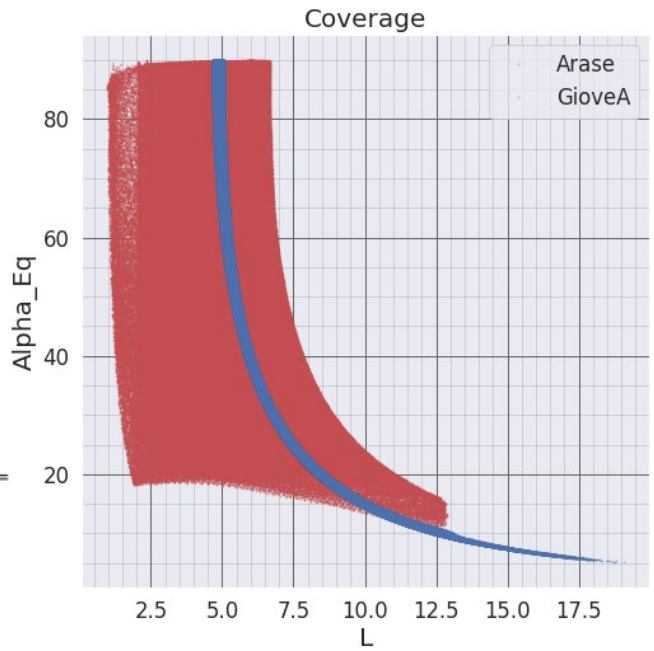
GNSS-HEO

Giove-A/SURF vs Arase/HEP-XEP







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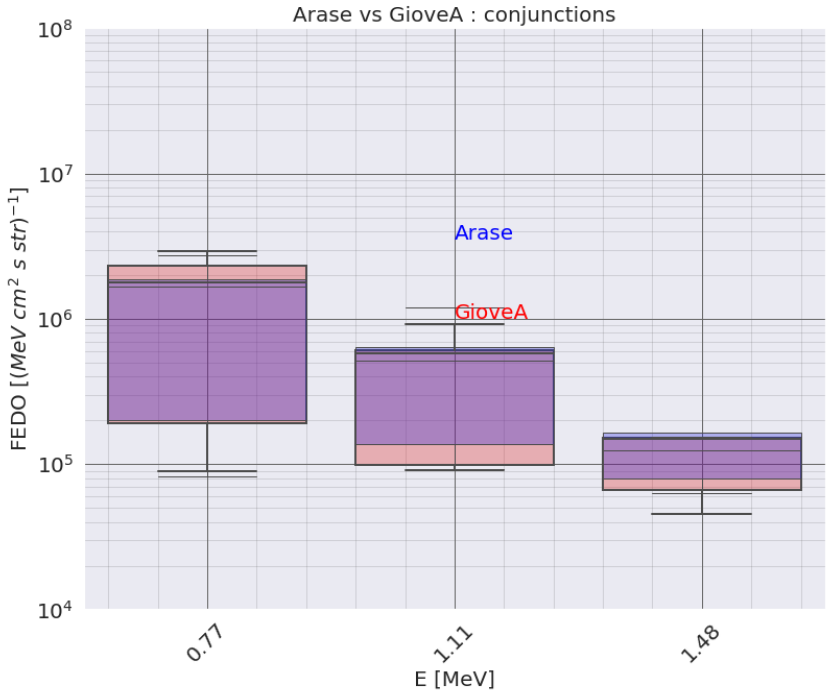
cad	5
cad_times	5
delta_l_max	0.2
delta_alpha_eq_max	5
delta_mlt_max	3
L_lims	[4.0, 7.0]
alpha_eq_lims	[85, 90]
mlt_lims1	[0, 24]
mlt_lims2	[0, 24]
kp_days	2
kp_lim	100



Ryden et al, https://doi.org/10.1109/TPS.2008.2001945

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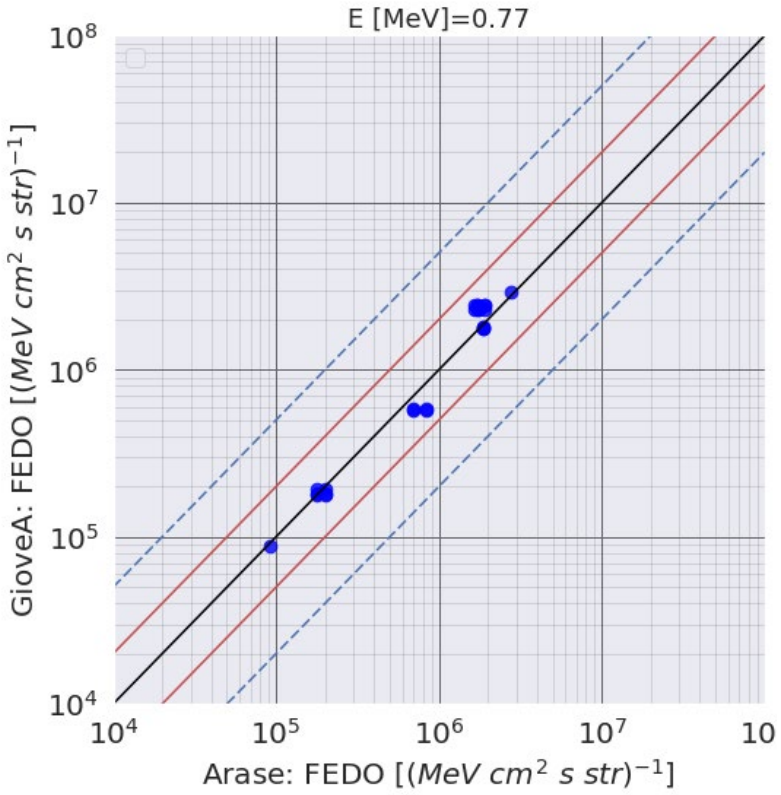
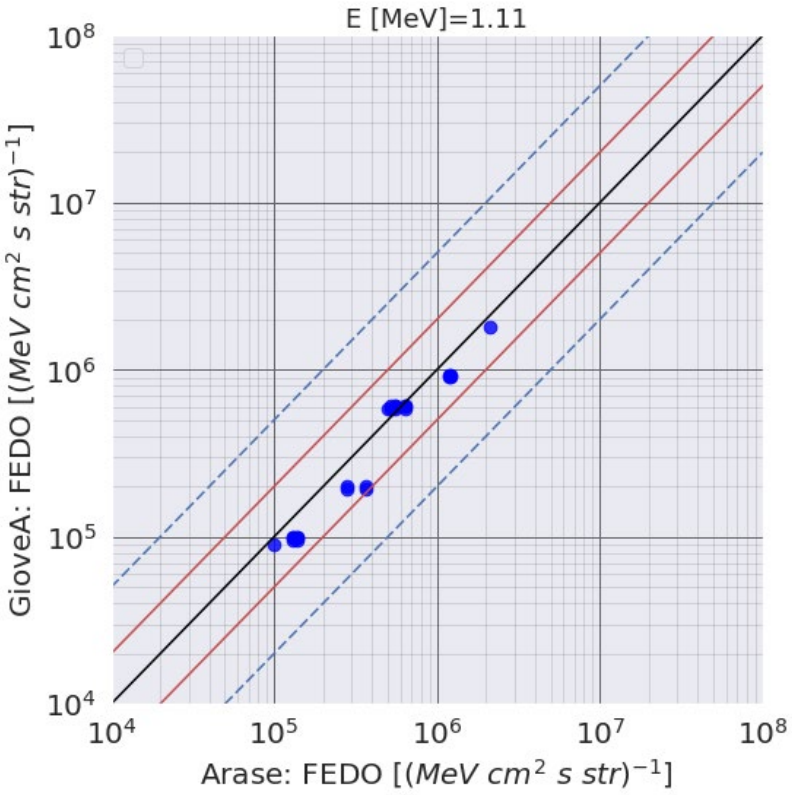
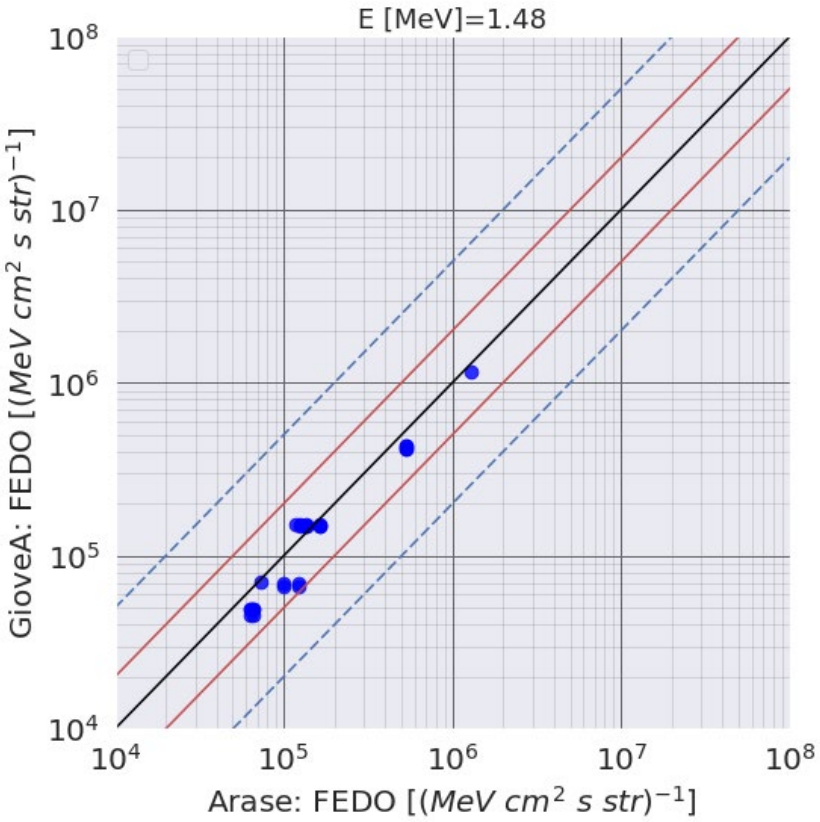
GNSS-HEO

Giove-A/SURF vs Arase/HEP-XEP







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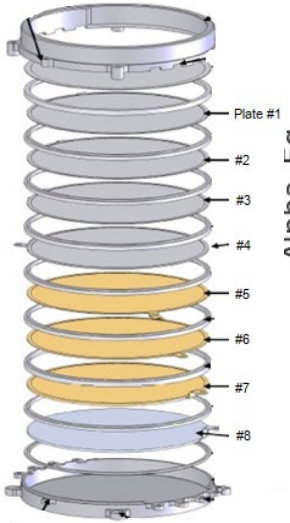
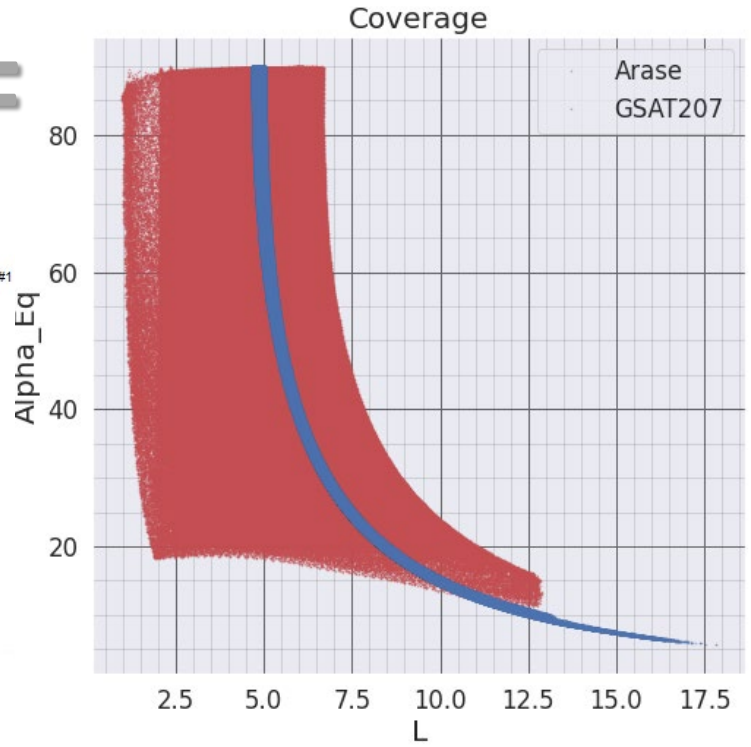
GNSS-HEO

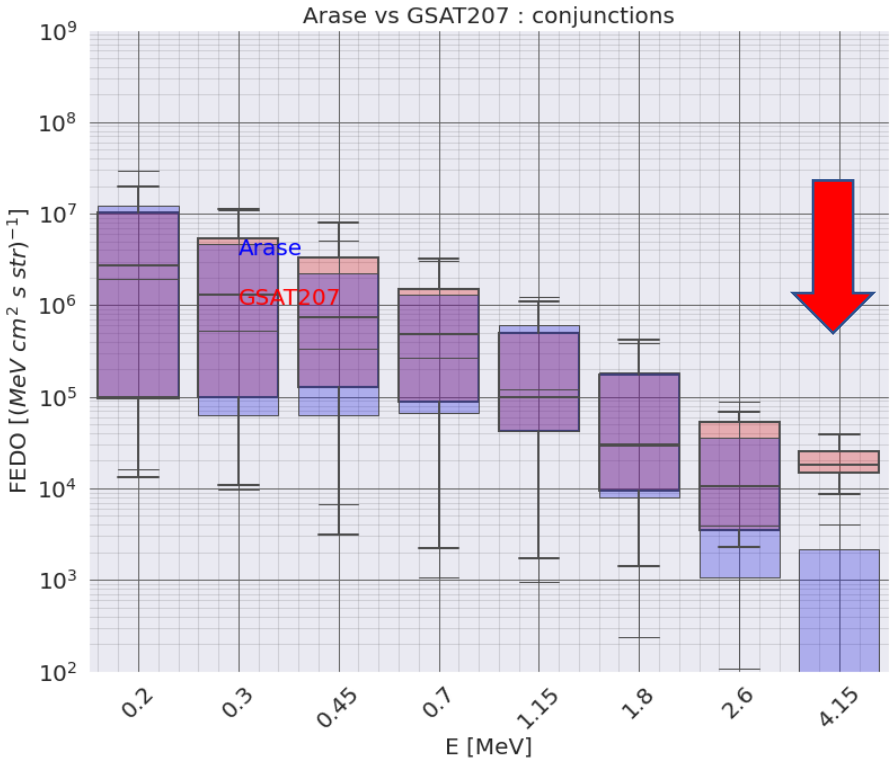
GSAT0207 vs Arase/HEP-XEP

SURF





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]
mlt_lims1	[0, 24]
mlt_lims2	[0, 24]
kp_days	2
kp_lim	100



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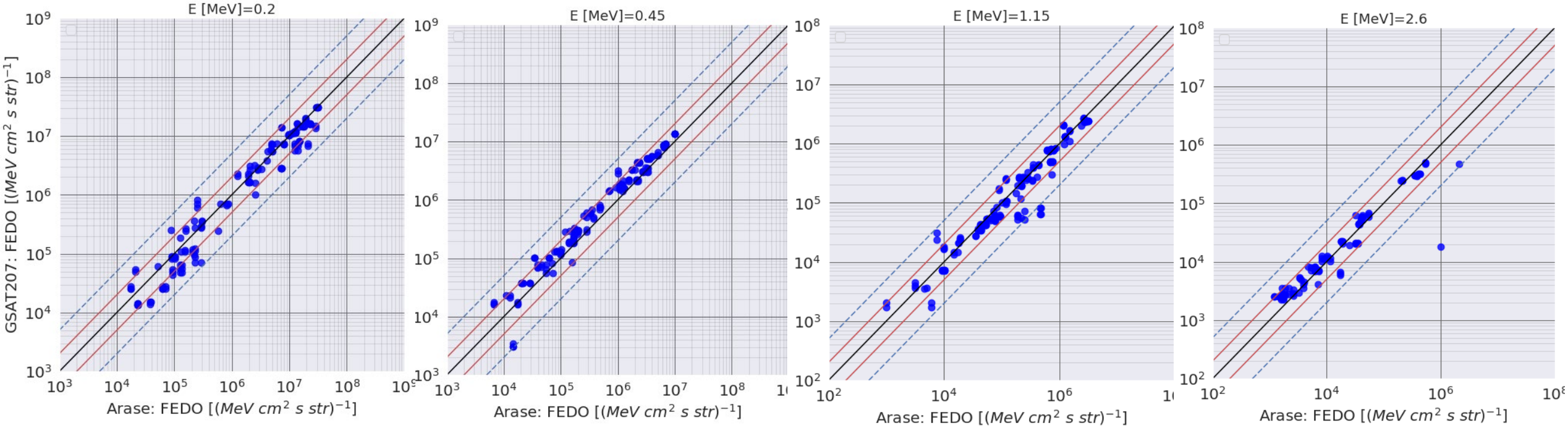
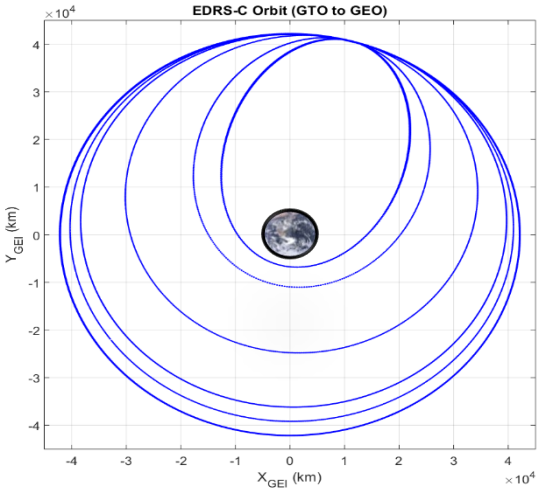
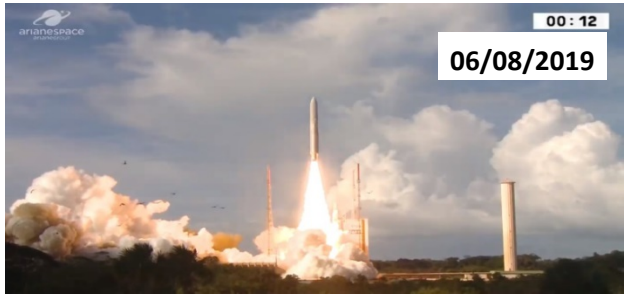
GSAT0207 vs Arase/HEP-XEP



Evaluation of EDRS-C/NGRM

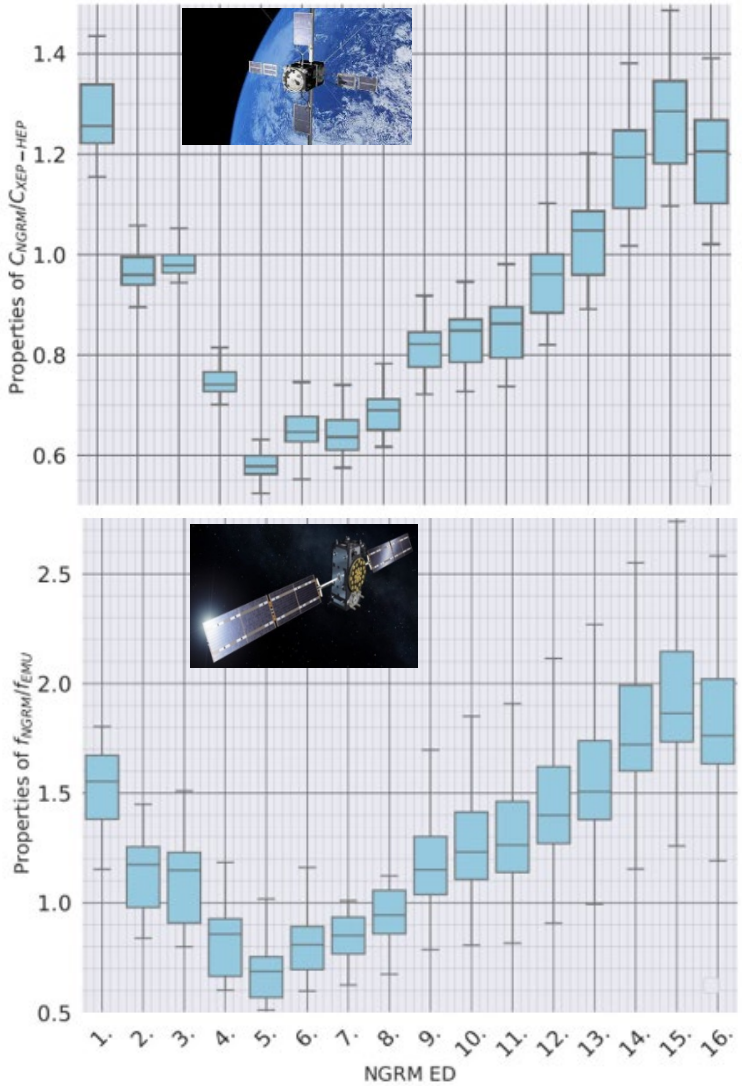




- Determine conjunctions
- Fold reference fluxes with the RFs of the target sensor

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

- Compare Level-0 with the reconstructed "reference" count-rates
- Rescale count-rates/RFs/ fluxes as long as they have been derived with a single multiplicative scaling factor (Bow-Tie analysis)



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

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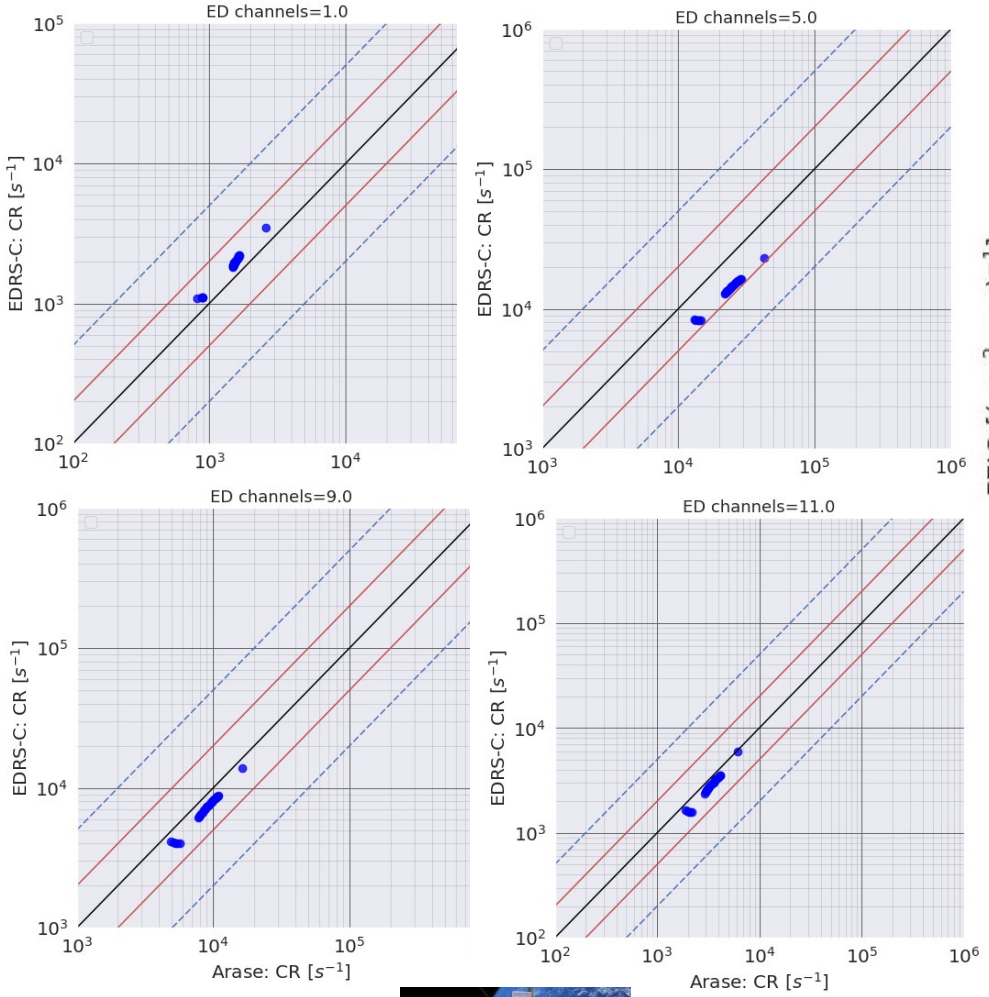
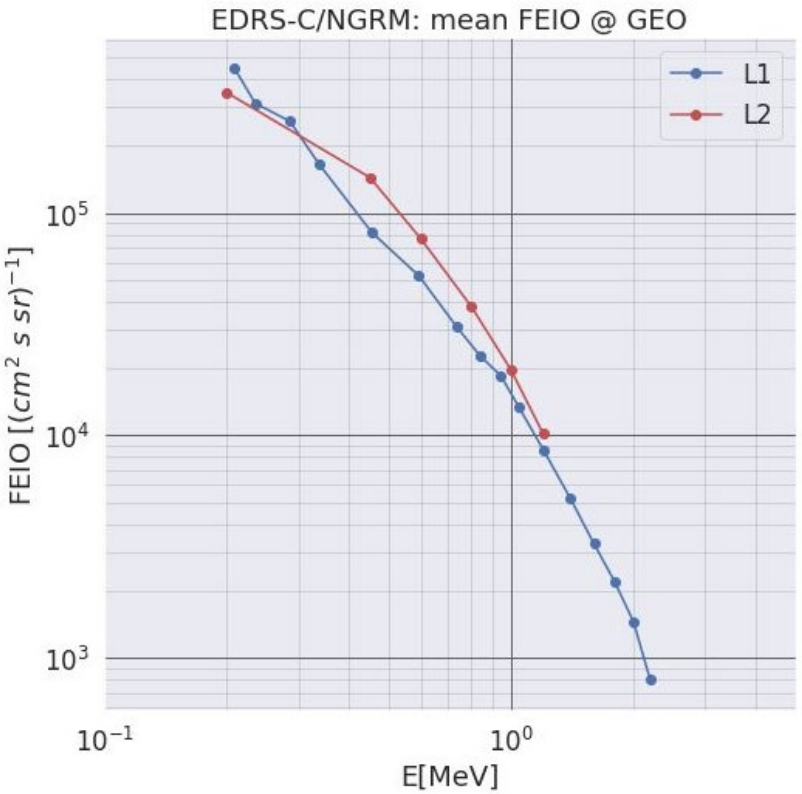
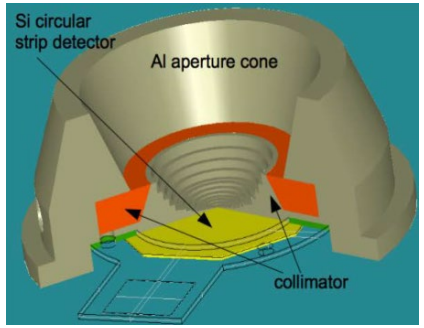
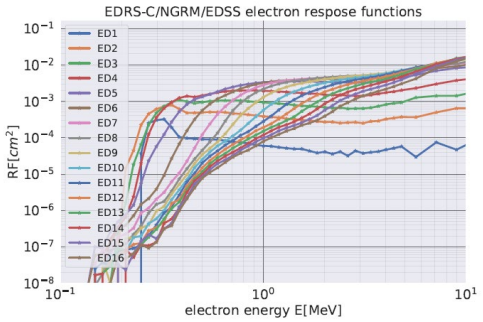
GTO - HEO

EDRS-C/NGRM Level-2 using Arase









GEO EDRS-C/NGRM mean electron integral flux spectra: Level-1 (blue points) versus Level-2 (red points)

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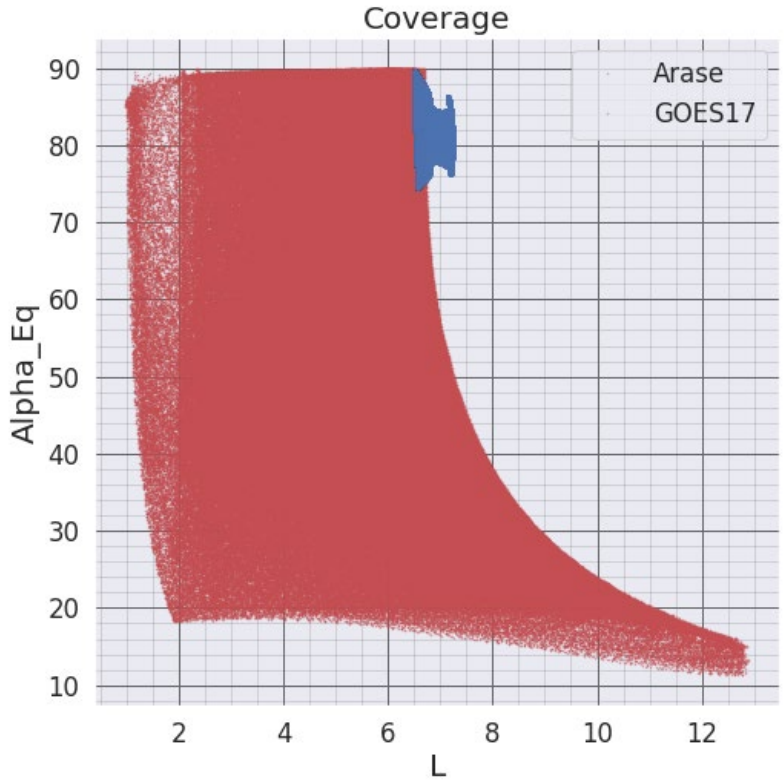
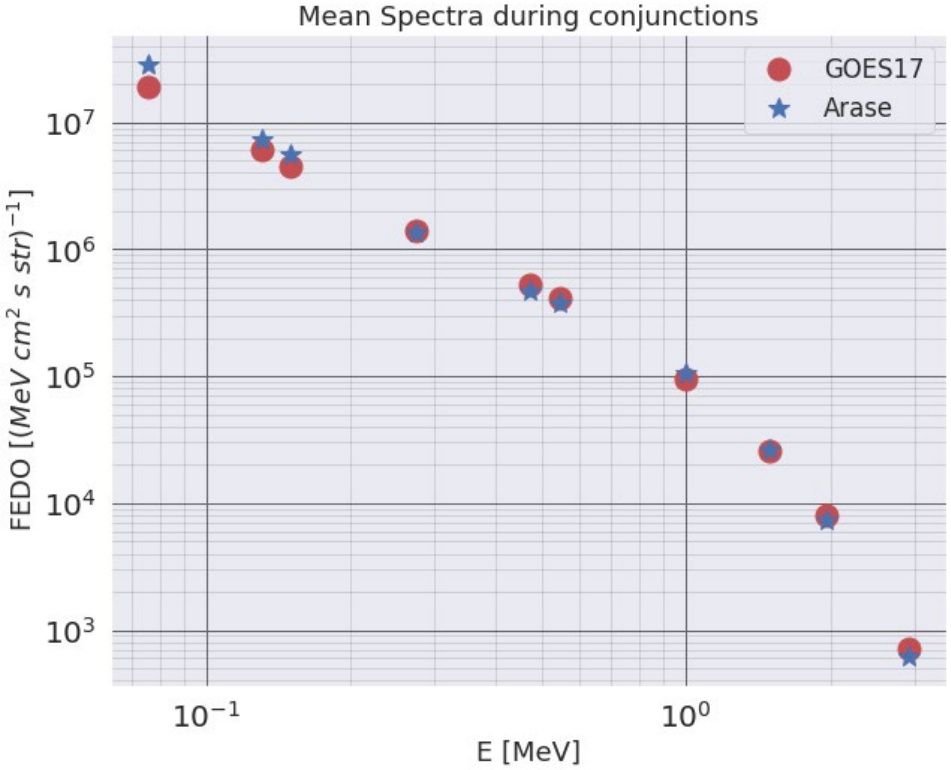
GOES 17/MPS-Hi vs Arase/HEP-XEP



type_orbit	HEO
cad	1
cad_times	0
delta_l_max	0.1
delta_alpha_eq_max	0.5
delta_mlt_max	24
L_lims	[1, 10]
alpha_eq_lims	[0, 90]
mlt_lims1	[0, 24]
mlt_lims2	[0, 24]
kp_days	2
kp_lim	200



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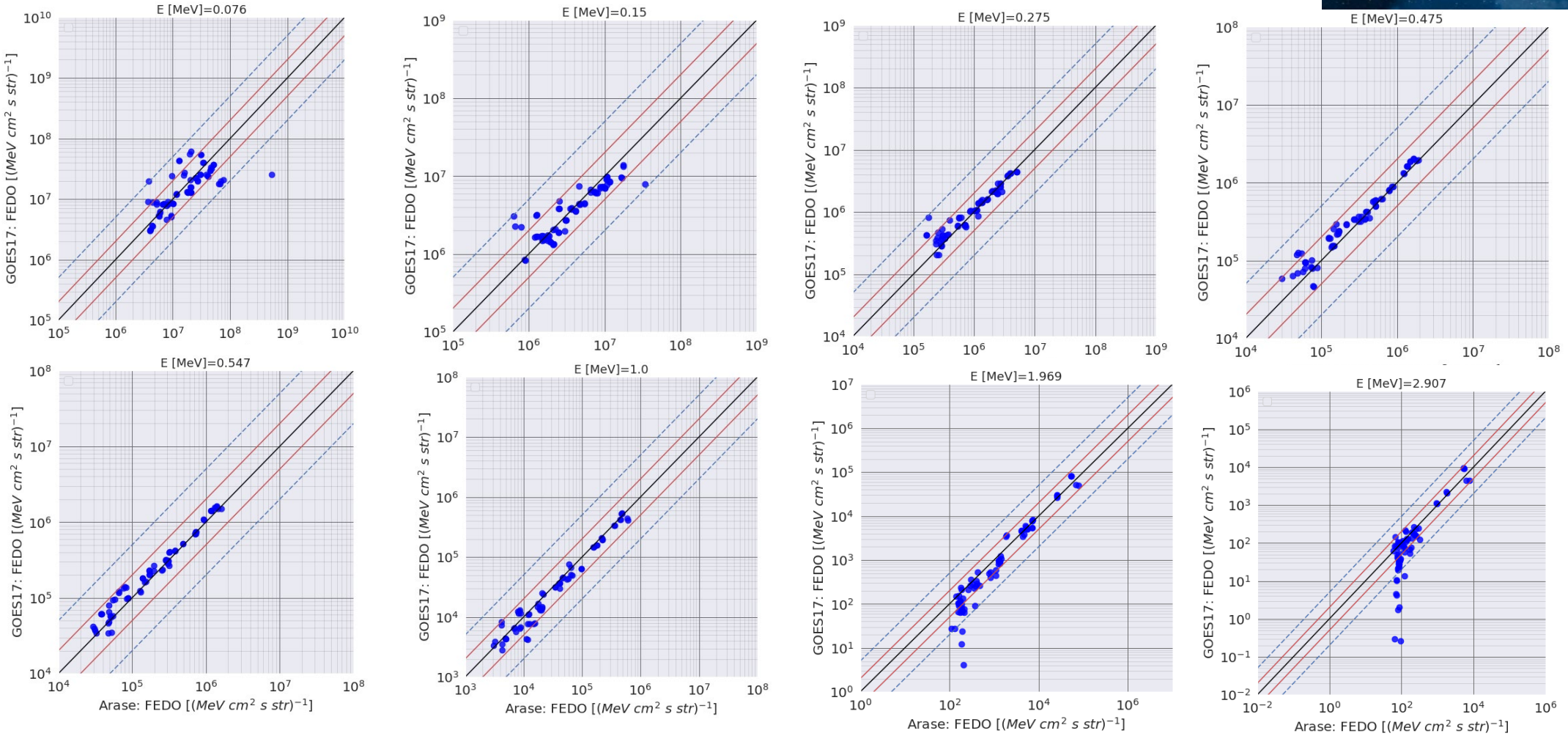
GOES 17/MPS-Hi vs Arase/HEP-XEP



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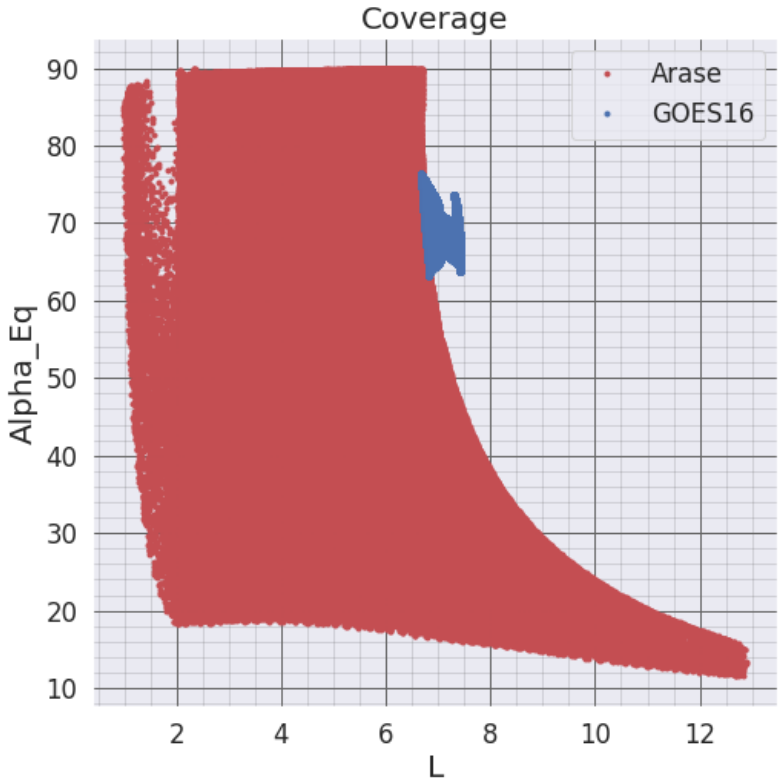
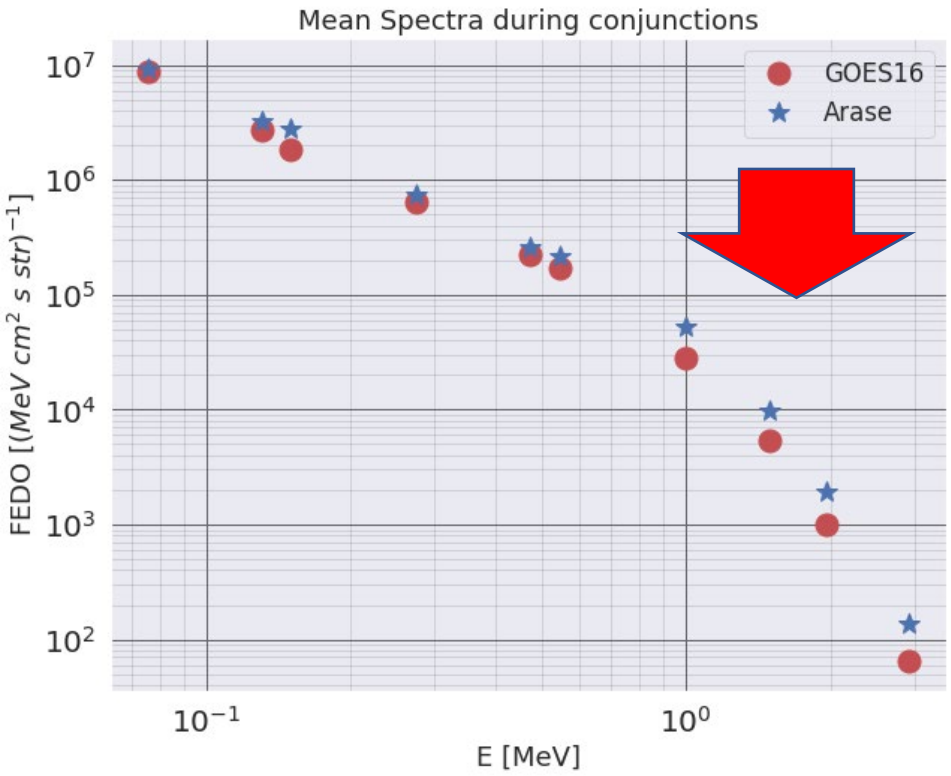
GOES 16/MPS-Hi vs Arase/HEP-XEP



type_orbit	HEO
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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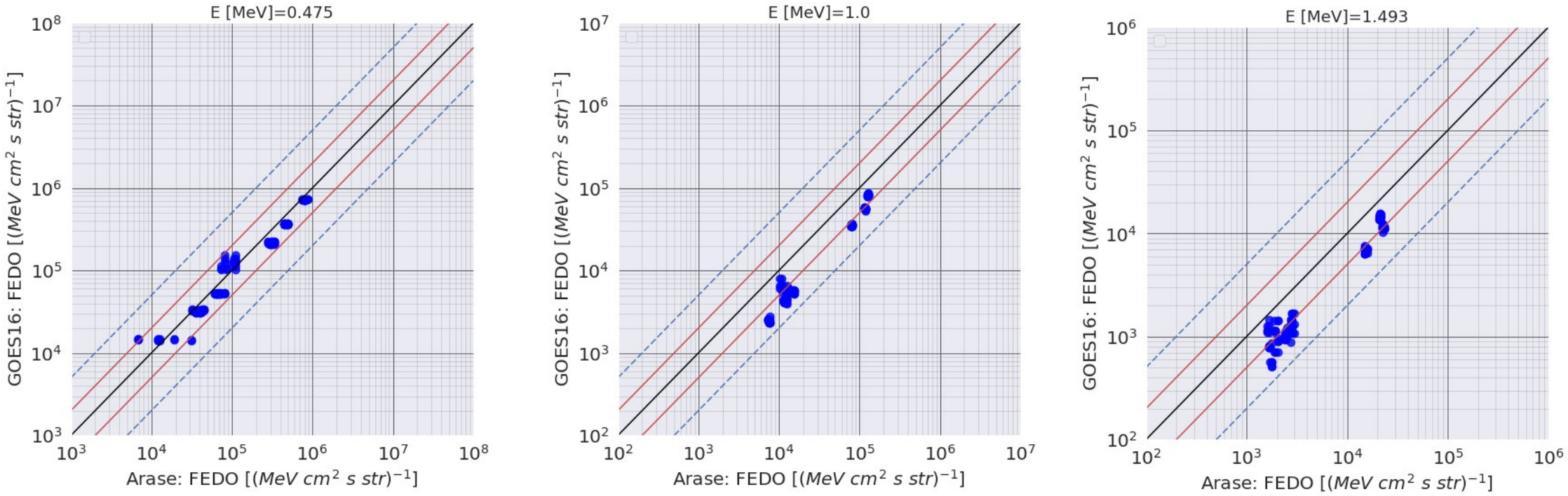
GOES 16/MPS-Hi vs Arase/HEP-XEP



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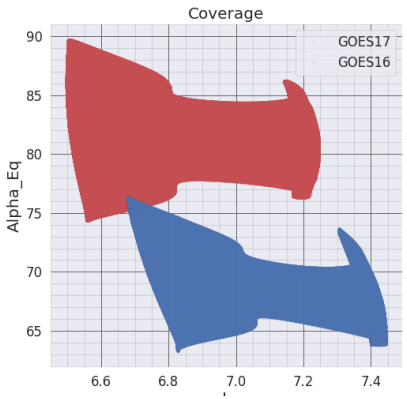
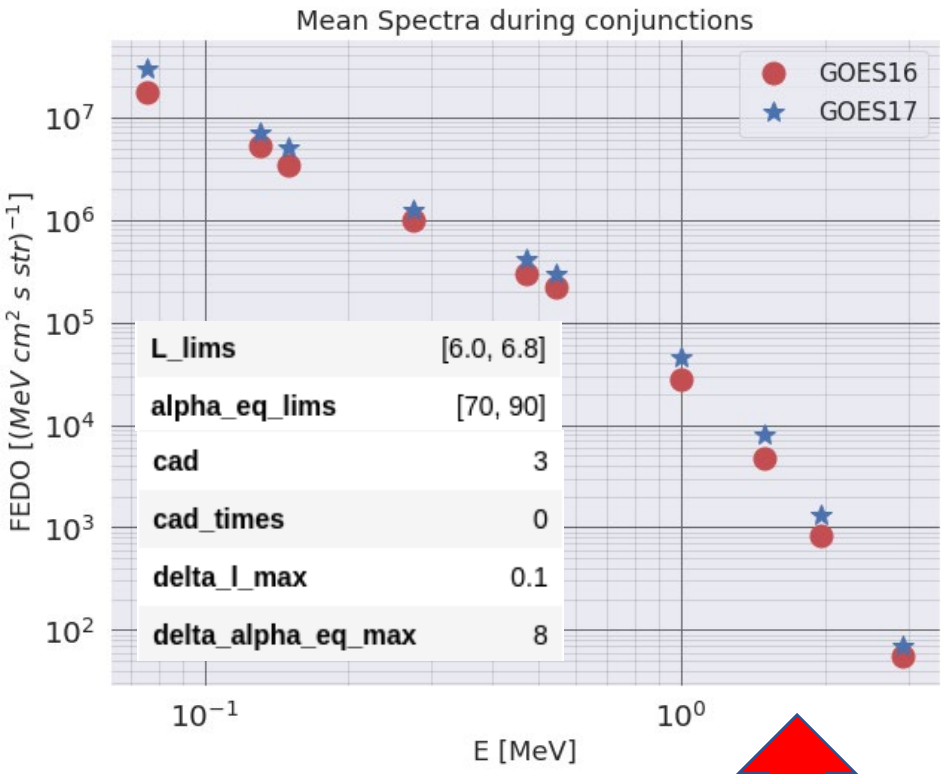
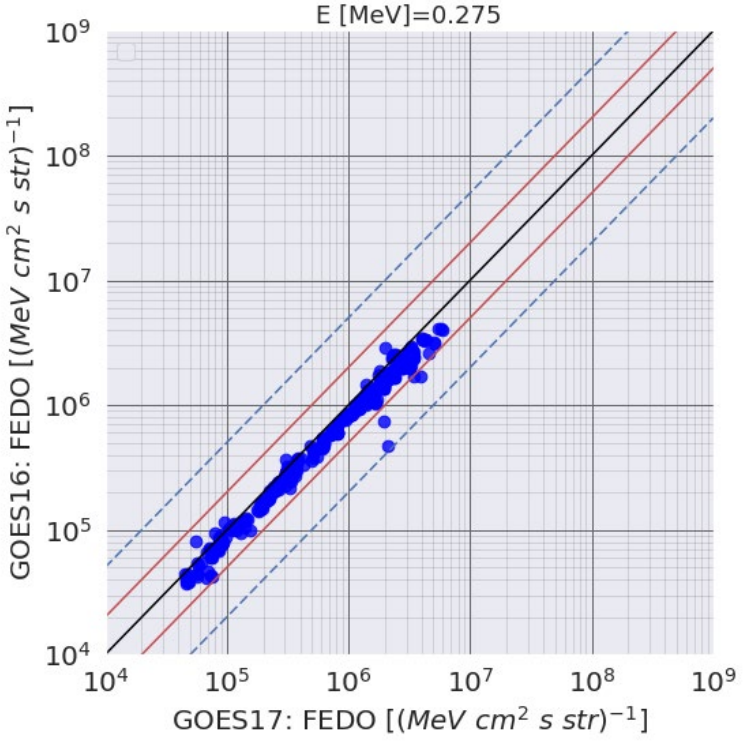
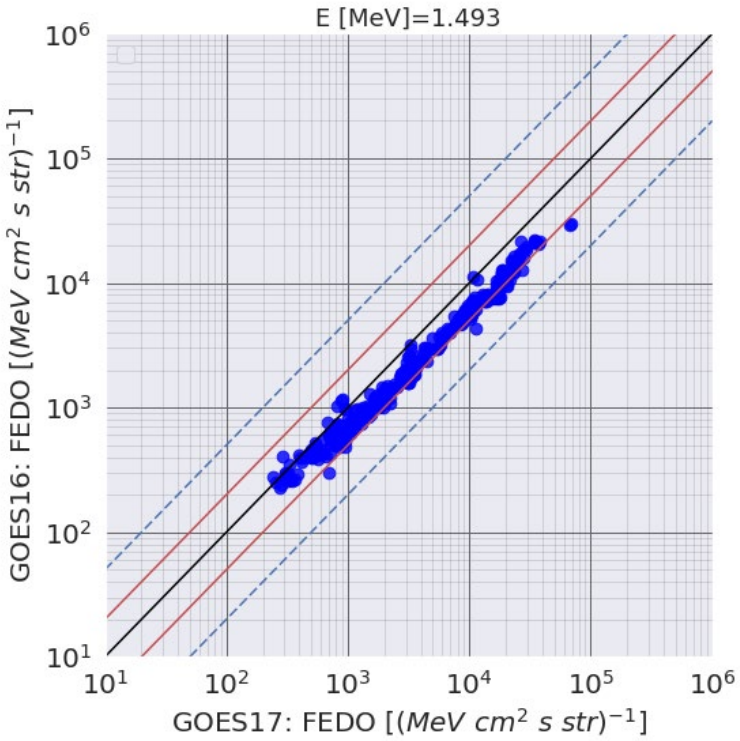
GOES 16/MPS-Hi vs GOES 17/MPS-Hi









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GSICS Global Space-based Inter-Calibration System

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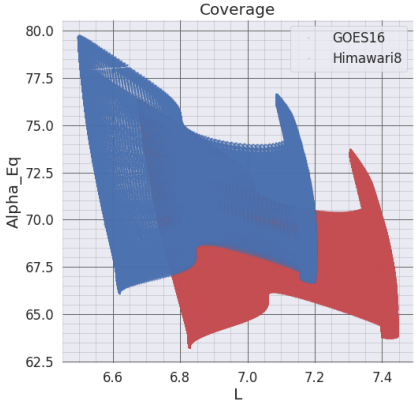
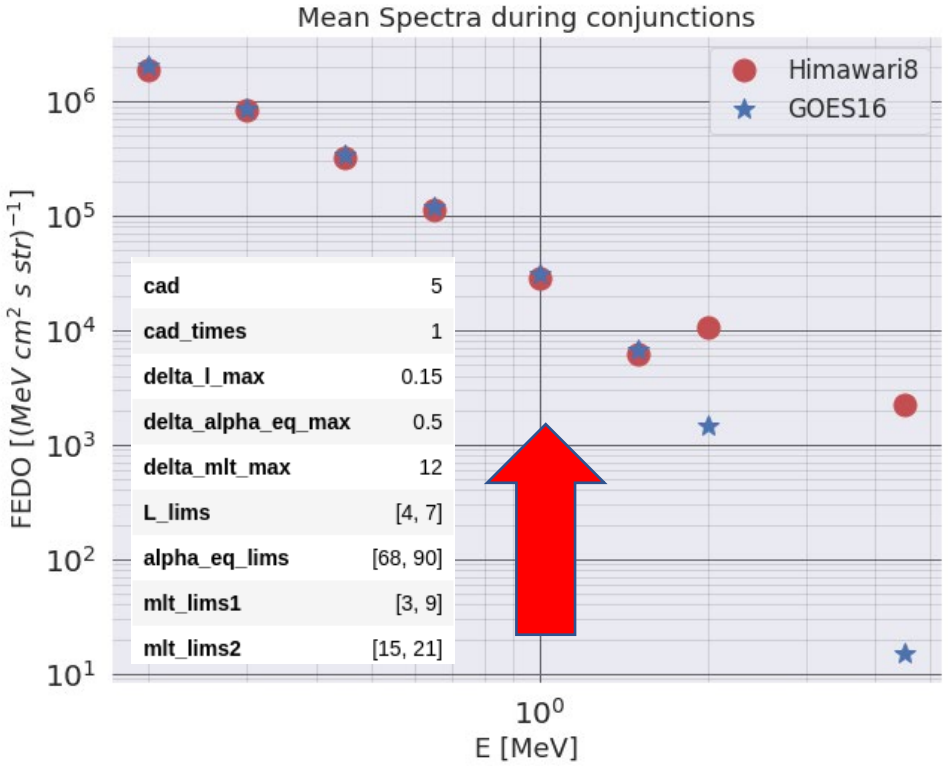
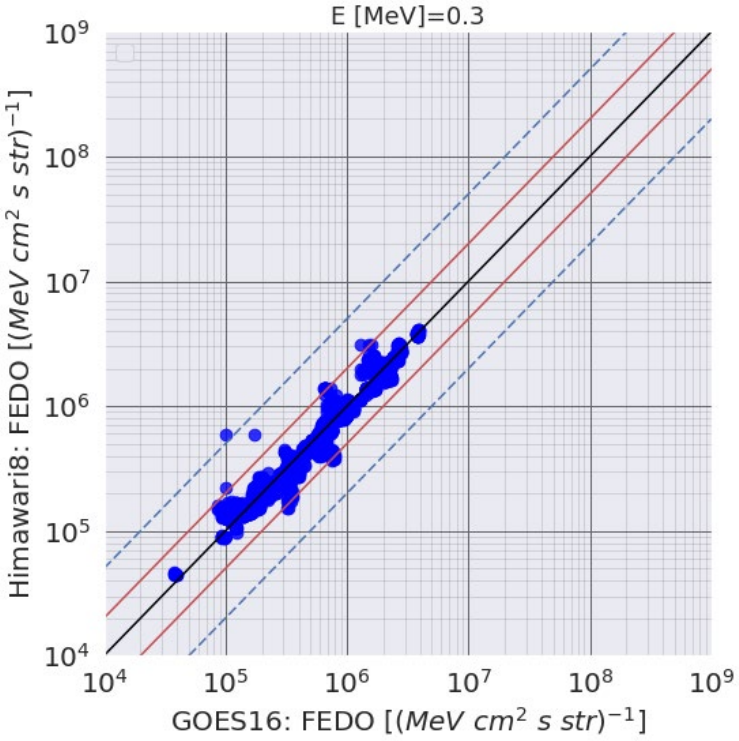
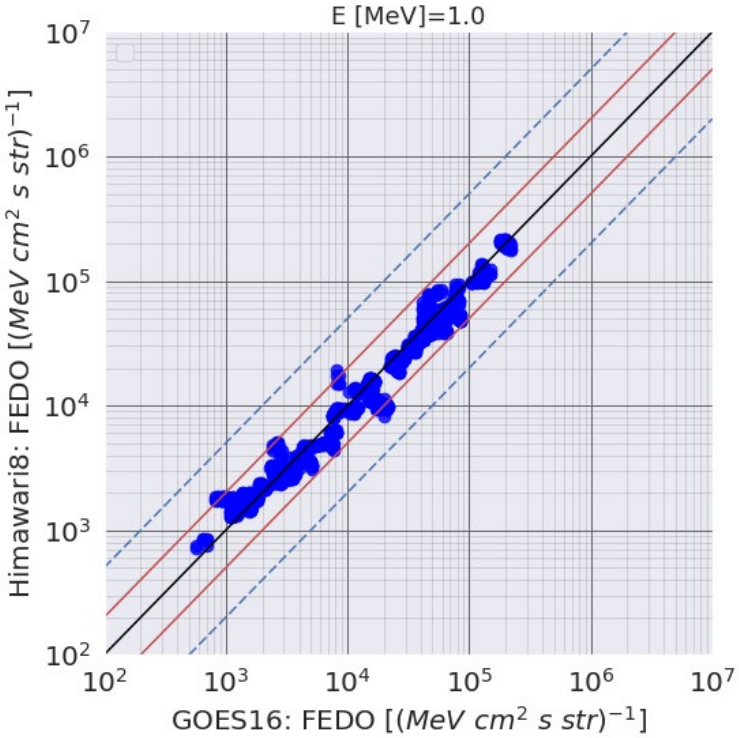
GEO - GEO

Himawari-8 vs GOES 16/MPS-Hi









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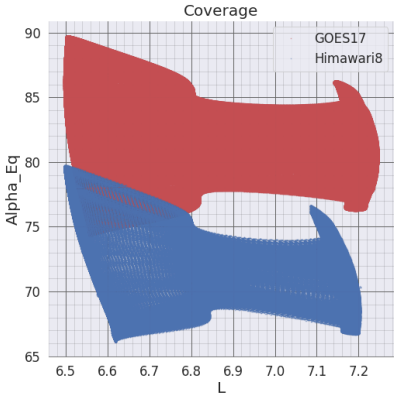
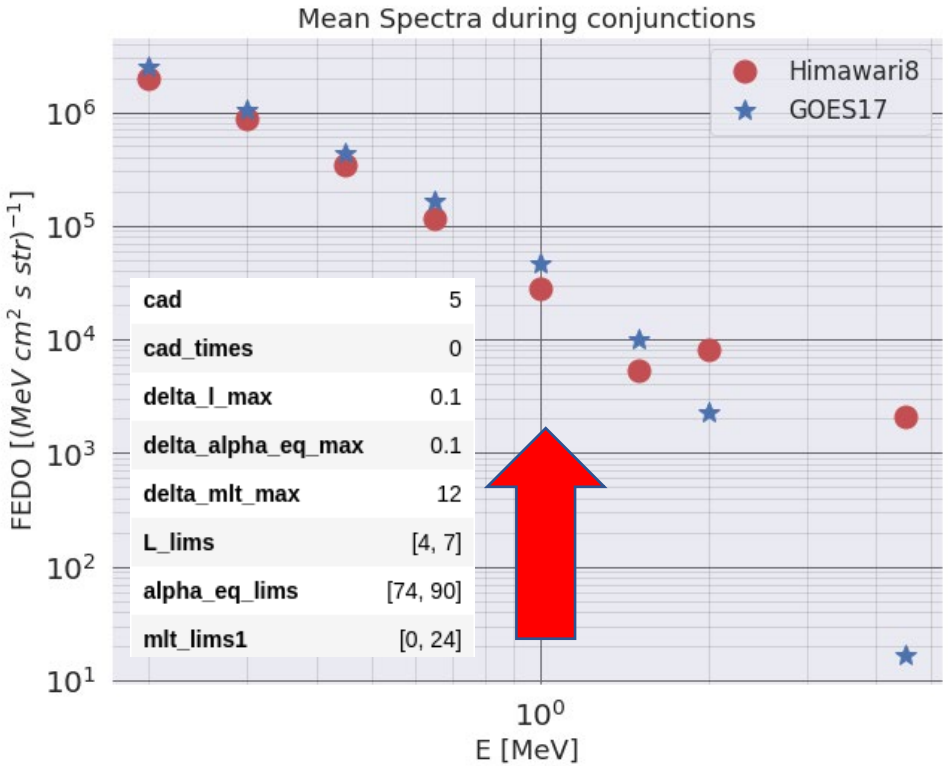
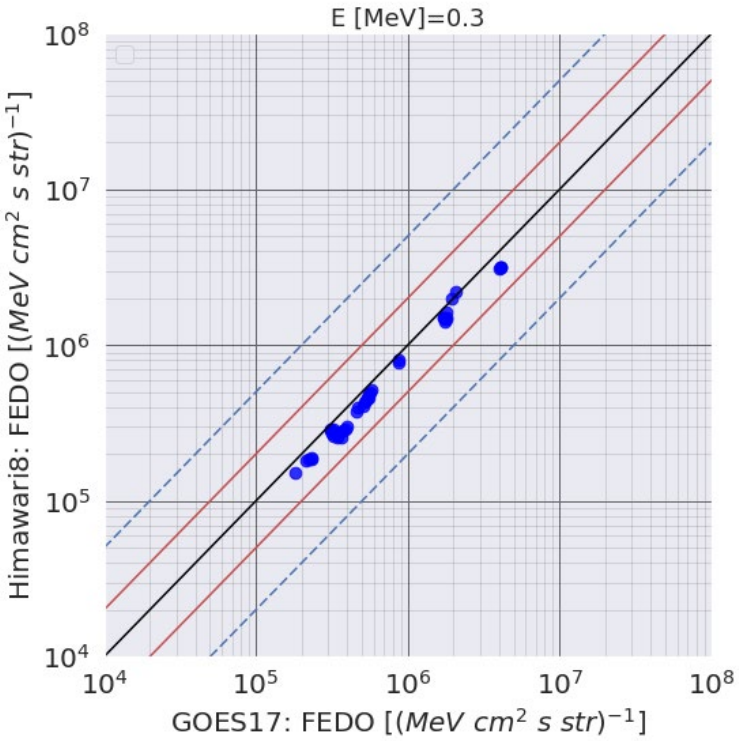
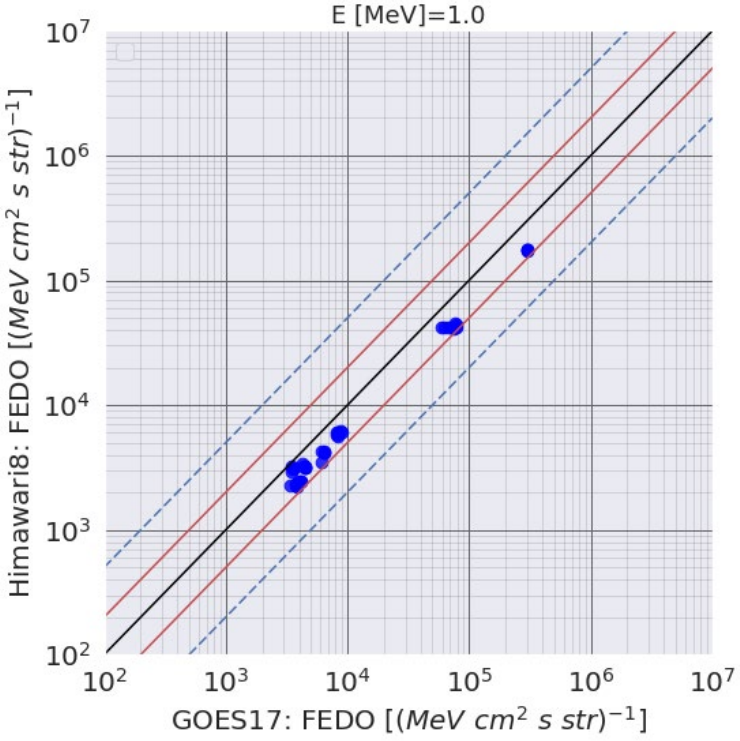
GEO - GEO

Himawari-8 vs GOES 17/MPS-Hi









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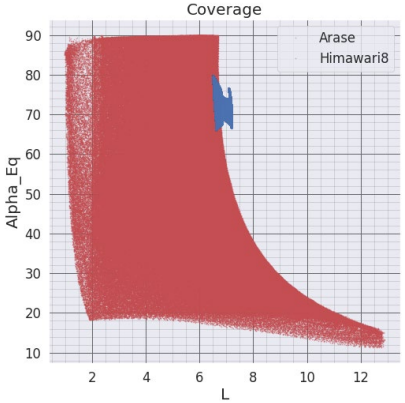
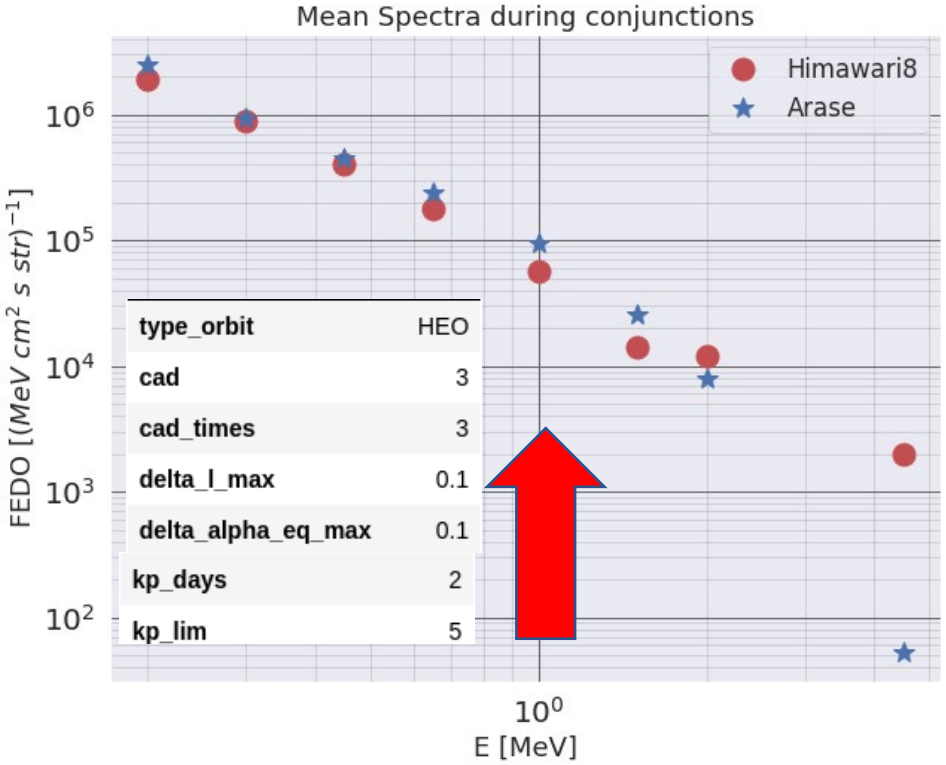
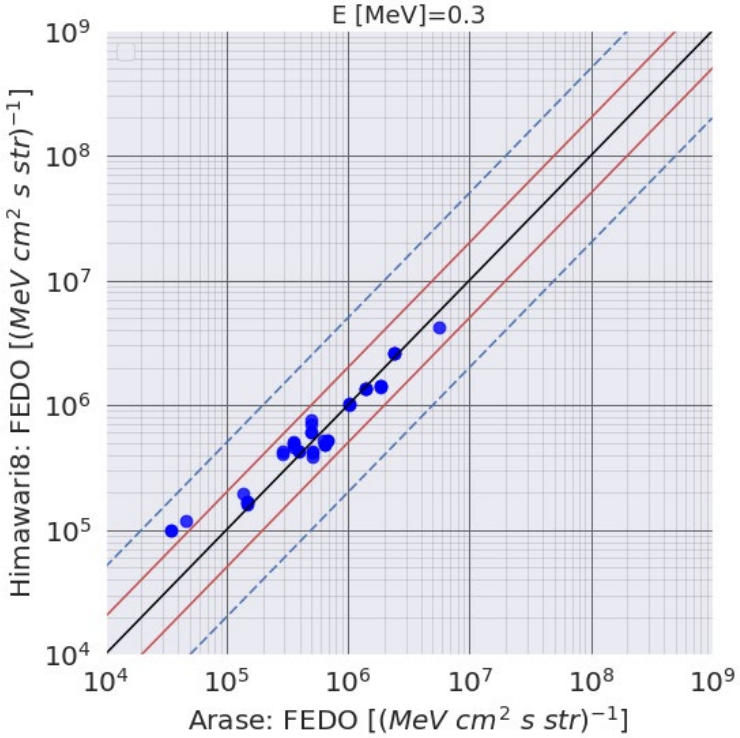
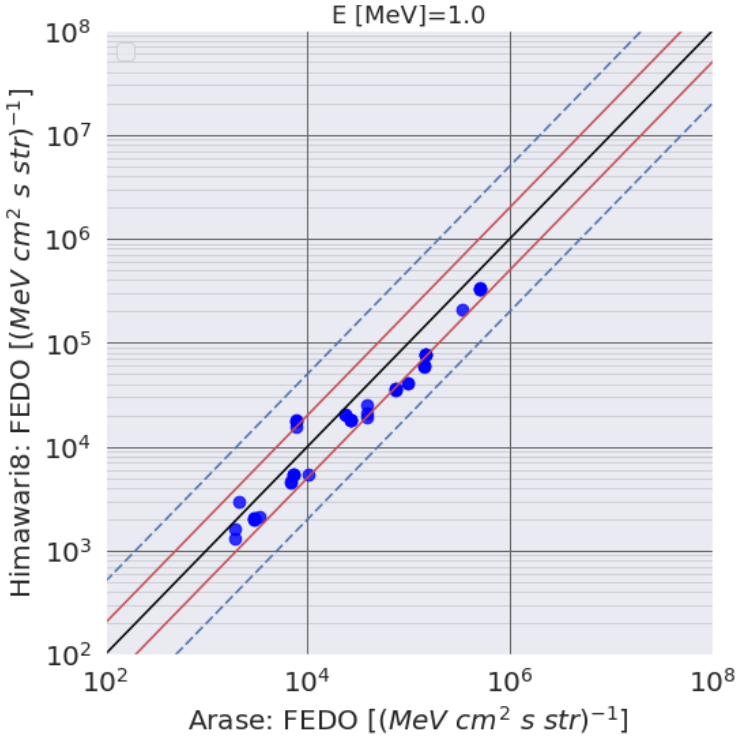
GEO - HEO

Himawari-8 vs Arase/HEP-XEP









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Discussion - lessons learnt

- Reference dataset (for GEO)?
- GEO-GEO calibrations studies:
  - selected time periods/periods: better control/understanding of conditions
  - maximum overlapping time periods: enhanced statistics
- Conjunction criteria: standardize selection procedures?
  - Kp index: intense geomagnetic conditions for high energy flux spectra
  - GEO-GEO: $\delta(MLT) \ll \varepsilon$ or $\delta(t) \ll \varepsilon$ - energy dependence
- Cross-calibrated datasets:
  - Definition of scaling factors
  - Error analysis and propagation – a missing feature
- Response Functions and accessibility of raw data
  - Calibrate sensor data (outputs) or Level 1 (fluxes)
- Measurements during GTO are invaluable:
  - More opportunities for cross-calibration studies
  - Calibration of measurements in flux-intense environments

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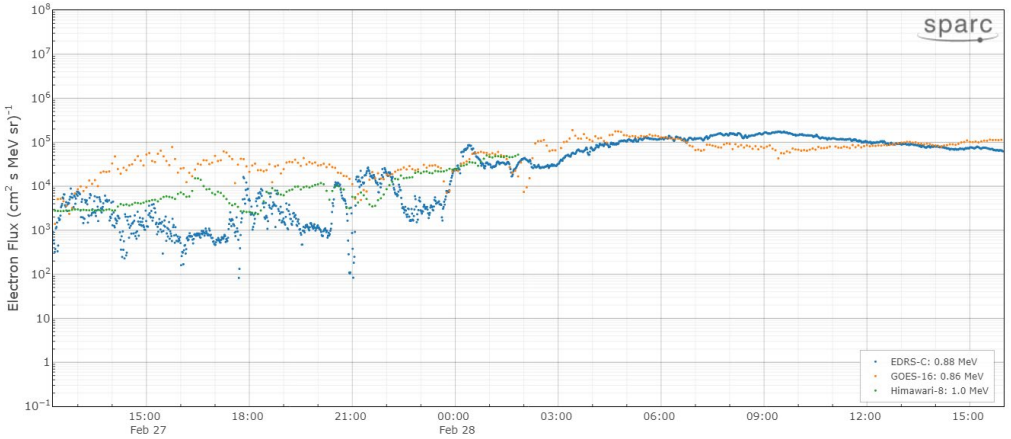
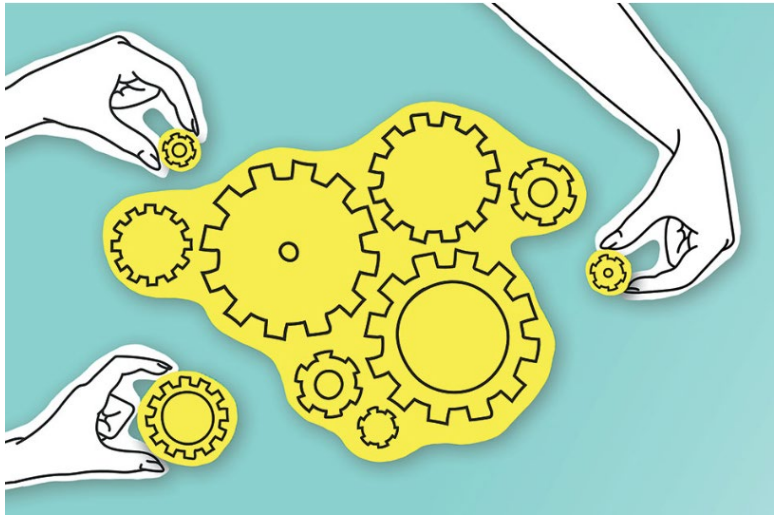
Discussion - lessons learnt

- Characteristic results presented
- Differences: **not significant!**
  - H8 - G16 < G17-Arase [E>1 MeV]
  - Arase-Merlin-GSAT-NGRM_L2
- Collaborations- interactions
- Recommendation on adds-on to the calibration scheme:
  - Conjunction conditions
  - Ignored physics
  - Diagnostics
  - Metrics
  - Plots-Statistics





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