GOES-R Magnetospheric Particle Sensors: Progress Report

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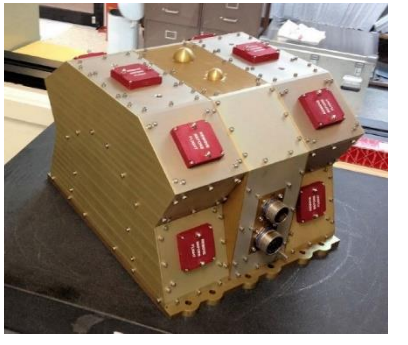
GOES-R+ Space Environment In-Situ Suite (SEISS): Magnetospheric Particles

Magnetospheric Particle Sensor – Low Energy (MPS-LO):

- Electrostatic analyzers (2 nested triquadrispheres)
- 14 angular zones (12 unique) spanning 180° north-south fan
- 2 dark zones for background correction
- 30 eV-30 keV electrons: 15 energies
- 30 eV-30 keV ions: 15 energies

Magnetospheric Particle Sensor – High Energy (MPS-HI):

- Solid-state telescopes (5 per species) arranged in N-S fan
- 50 keV-4 MeV, >2 MeV electrons: 11 energy bands
- 80 keV-10 MeV protons: 11 energy bands
- Two hemispherical dosimeters:
  - 100 mil (2.54 mm) Al: >1.2 MeV electrons, >22 MeV protons
  - 250 mil (6.35 mm) Al: >2.8 MeV electrons, >37 MeV protons



Magnetic field vector from GOES tri-axial fluxgate magnetometer is essential for calculating pitch angle for each telescope / zone and for conversion of flux to phase space density as a function of the first adiabatic invariant

Each SEISS suite also includes an Energetic Heavy Ion Sensor (EHIS) and two Solar and Galactic Proton Sensors (SGPS) [talk by Brian Kress this afternoon]

SEISS MPS designed, built, tested and calibrated by Assurance Technology Corporation

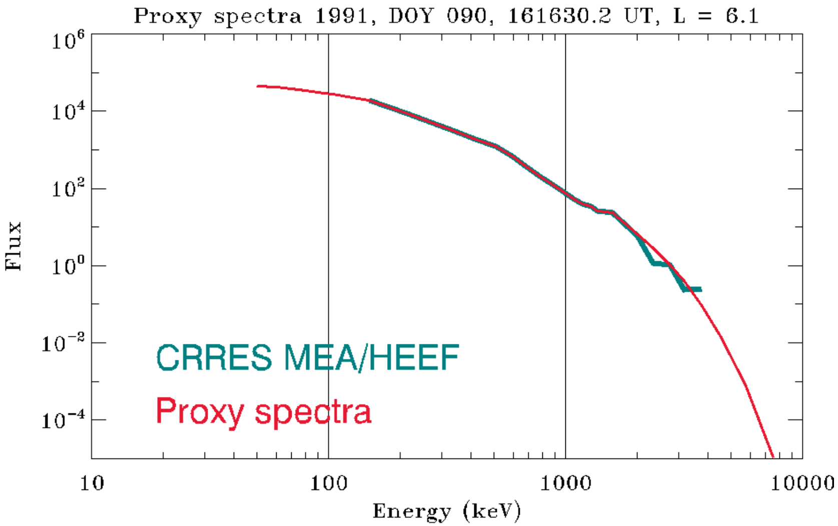
MPS-HI Energy Channels

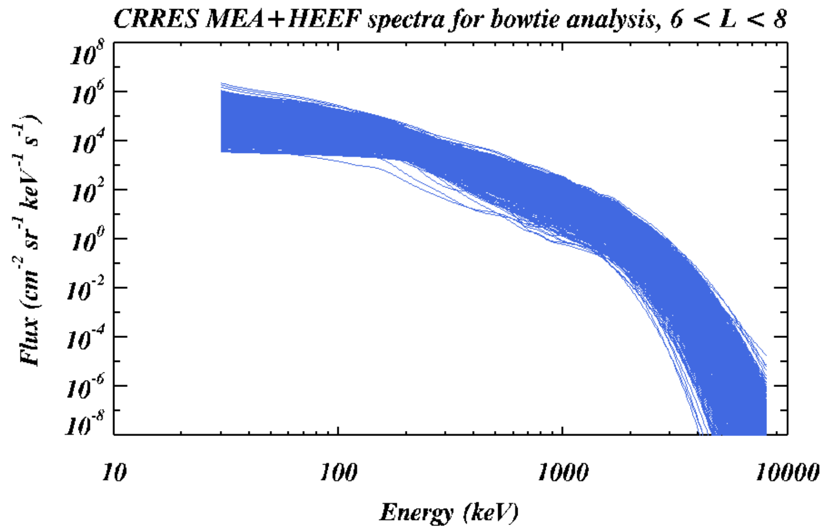
Electron Channel	Energy Range (keV)	Bowtie Energy (keV)	Proton Channel	Energy Range (keV)
E1S	50-80	59	P1	80-115
E2	90-145	118	P2	105-148
E3+E3A	145-230	181	P3	148-212
E4	230-325	272	P4	212-309
E5	325-460	378	P5	309-536
E6	460-705	548	P6	536-720
E7	705-1360	855	P7	720-1000
E8	1360-1785	1493	P8	1000-1900
E9	1785-2685	1967	P9	1900-3200
E10	2685-4345	2903	P10	3200-6500
E11	>2000	>2075	P11	6500-12000
E10a*	4345-5660	>4111		

** Not reported in real time!*

Geometry-Energy Factors for Real-Time Processing Derived Using Bowtie Analysis of CRRES Spectra

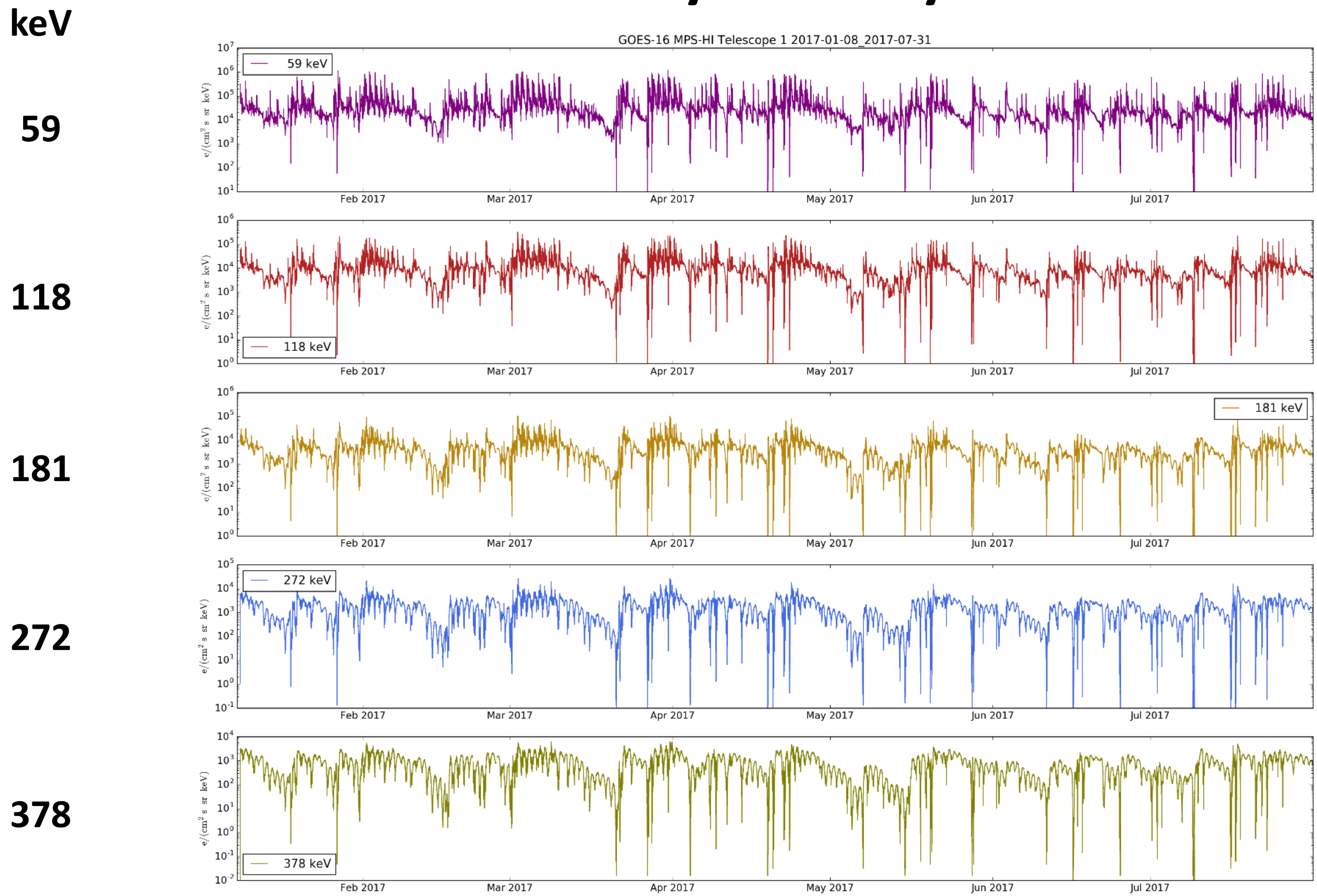
- Cross-calibrated CRRES Medium Electron Sensor A (MEA) and High Energy Electron Fluxmeter (HEEF) data set from ViRBO [Johnston, Lindstrom and Ginet, 2011]
- July 1990 – October 1991 in a geosynchronous transfer orbit
- MEA: 148-1582 keV, 17 channels
  - Higher resolution than MPS-HI
  - Considered the 'gold standard'
- HEEF: 0.65-7.5 MeV, 11 channels
- Use omnidirectionally averaged spectra between 6 ≤ L < 8 in which 1.6 MeV MEA and HEEF observations agree to within 2x
  - ~30,000 such spectra in 1990
  - Fit HEEF spectra ≥1.6 MeV to exponentials due to poor counting statistics
  - Extrapolate down to 30 keV by fitting exponentials to lowest-energy MEA channels





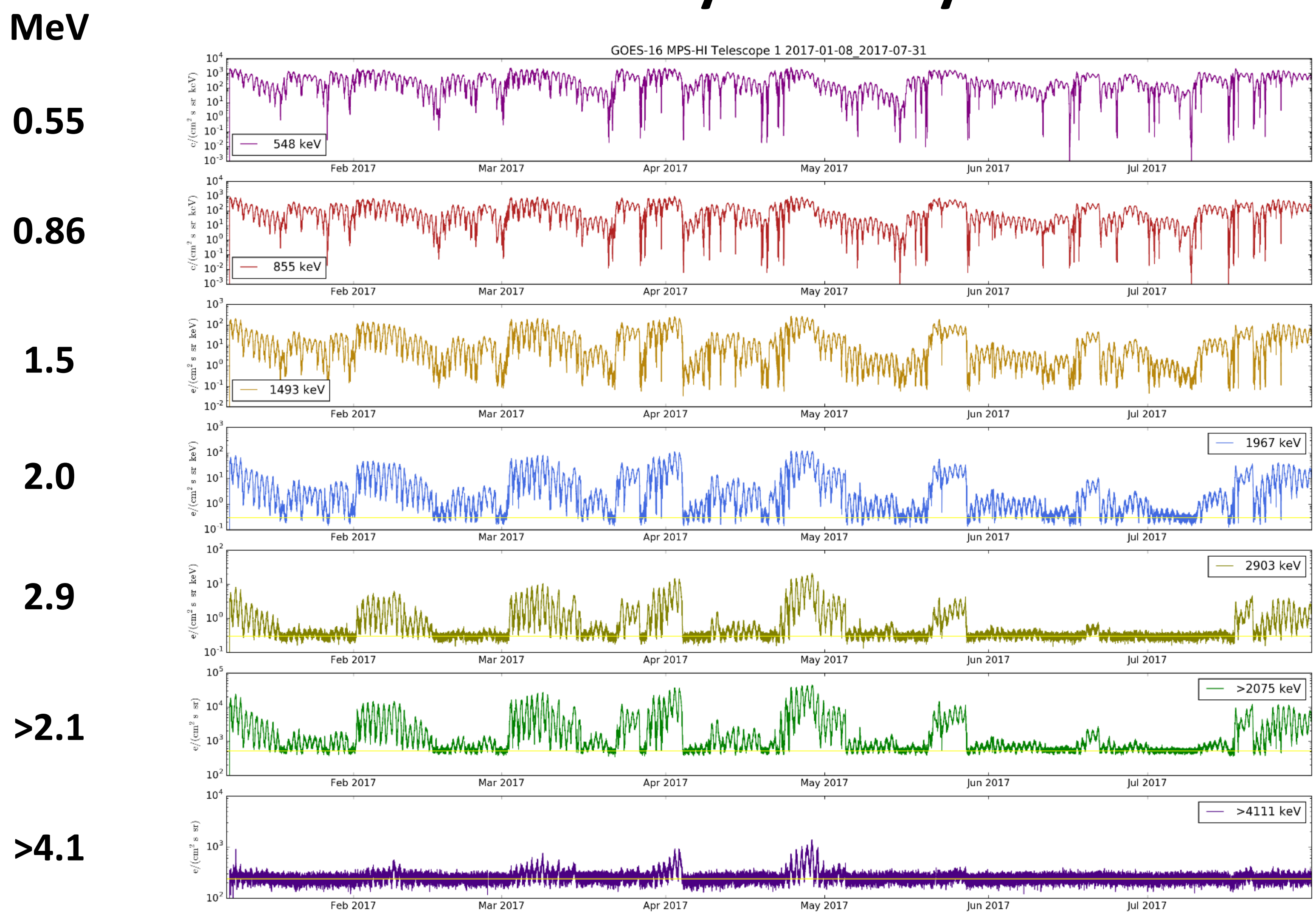
1000 randomly selected CRRES MEA + HEEF spectra from 1990 used for bowtie analysis

GOES-16 59-378 keV electrons, 08 January – 31 July 2017



These GOES-16 data are preliminary, non-operational data and are undergoing testing.
Users bear all responsibility for inspecting the data prior to use and for the manner in which the data are utilized.

GOES-16 0.55-4.1 MeV electrons, 08 January – 31 July 2017



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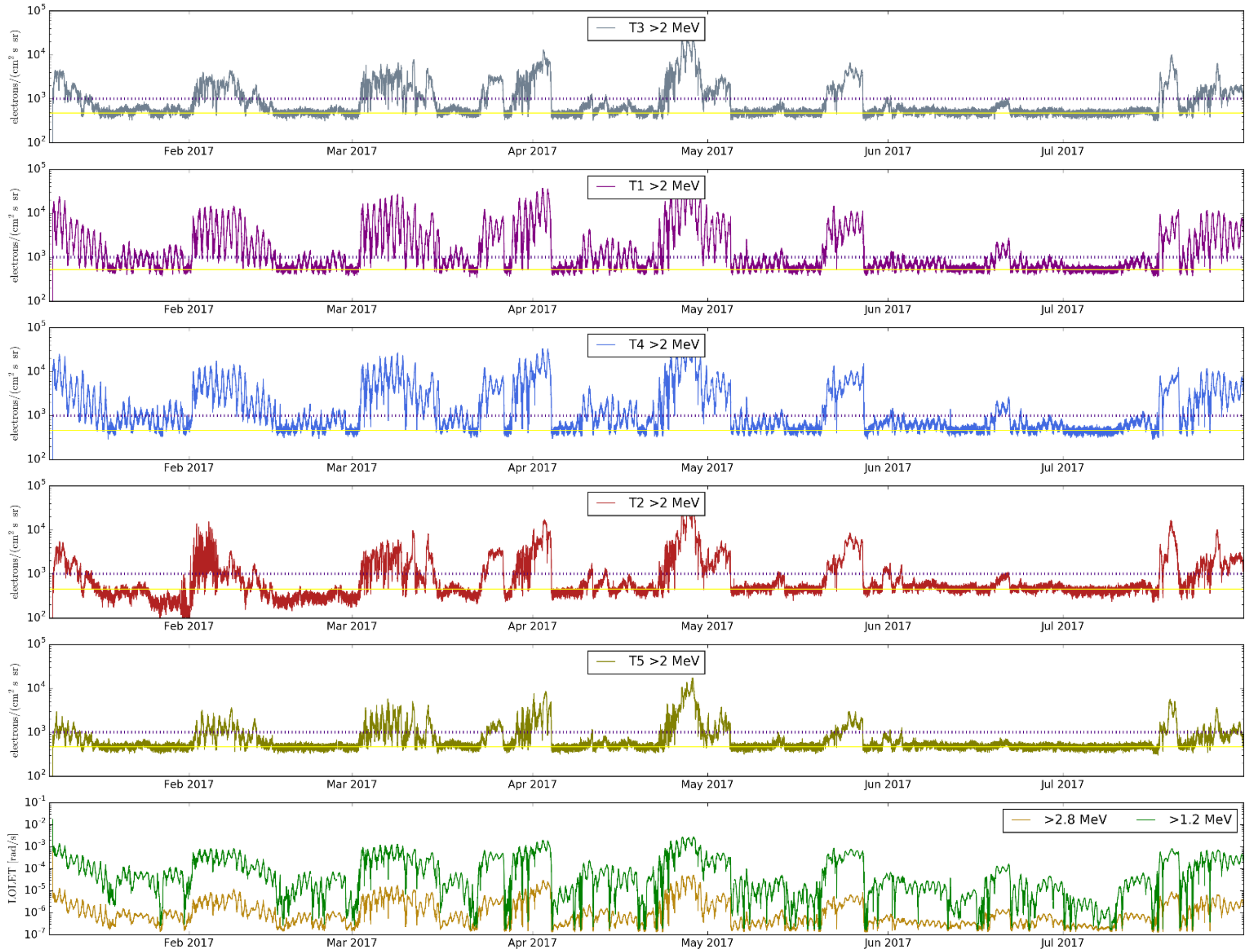
>2 MeV Channels: GOES 8-15 vs. GOES-16+

- Since 1974, >2 MeV electrons have been measured by NOAA in geostationary orbit
  - "The single electron channel was intended primarily to provide an independent monitor of the electron environment critical to the X-ray sensor performance…" [Grubb, 1975]
- Since c. 1980, these data have been used to diagnose internal charging effects
- Since 1995, SWPC has issued real-time alerts when GOES-East >2 MeV electron fluxes exceed 1000 electrons/(cm^2 sr s) [Wrenn and Smith, 1996]
  - GOES-West >2 MeV fluxes factor of 2.5 greater than at GOES-East [Meredith et al., 2015]

	EPS/EPEAD (8-15)	MPS-HI (16+)
Detector type	Dome	Solid-state telescopes (5)
Geometric factor	0.05 cm^2 sr	0.0012 cm^2 sr
Number of look directions	2	5
Look directions, centers	eastward, westward	±70°, ±35°, 0° (N-S fan)
Full width, each look	~110°	30°
Typical central pitch-angles	90°	5°, 30°, 65°, 100°, 135°
Proton contamination	> 17 MeV	>300 MeV
Background equivalent flux level (uncorrected)	~20 el/(cm^2 sr s)	~400 el/(cm^2 sr s)

GOES-16 >2 MeV Electrons, 08 January – 31 July 2017

Pitch Angles



T3	~135°
T1	~100°
T4	~65°
T2	~30°
T5	~5°
Dosimeters	

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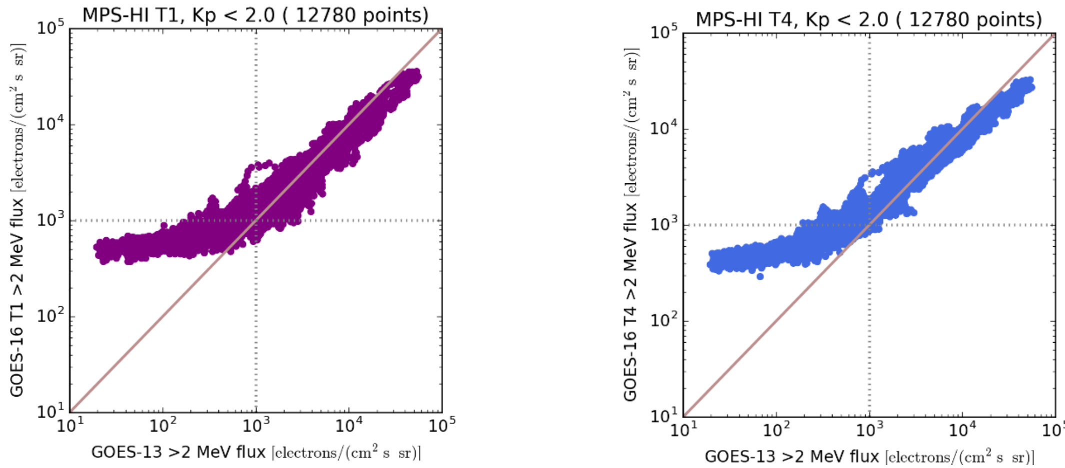
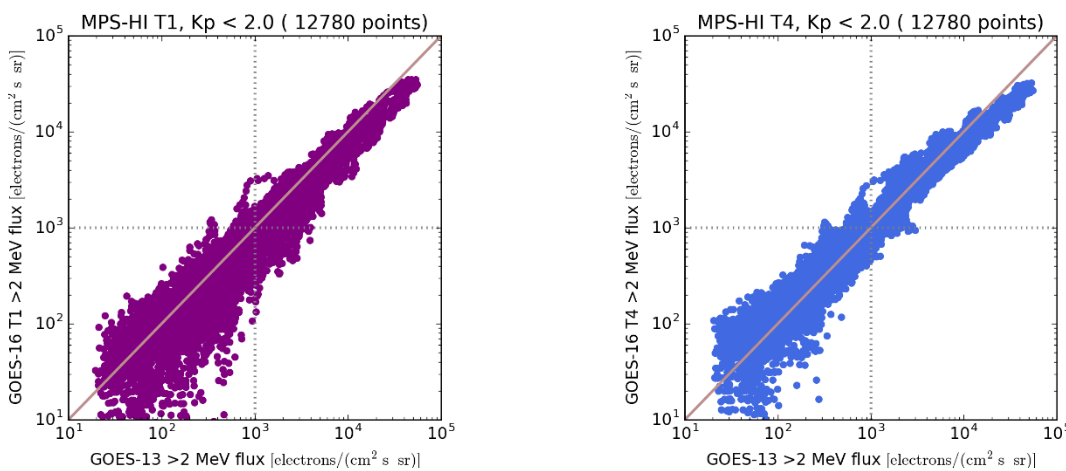
GOES-16 vs. -13 >2 MeV Electrons (Telescopes 1 and 4), 8 January-11 April 2017, Kp < 2o

Backgrounds not removed



Backgrounds removed



Cross-comparisons over the first 3 months of GOES-16 operations show that MPS-HI Telescopes 1 and 4 provide comparable >2 MeV flux measurements to GOES-13, can be used as the basis for future alerts.

MPS-LO: Origins

- H. Farthing et al. (1982), 'Differential Spacecraft Charging on the Geostationary Operational Environmental Satellites':

  The present Space Environment Monitor on GOES does not include the capability for monitoring particle populations of energies responsible for spacecraft charging. The requirements were set for GOES before the charging was recognized. Addition of the instrument necessary has been identified by NOAA's Space Environment Laboratories as a high priority for future operational satellites. Unfortunately present programmatic and funding limitations will likely prevent the addition of this capability until the late 1990's.

- J. Mazur (ed.) (2003), 'Workshop on Energetic Particle Measurements for the GOES R+ Satellites':
  - "The workshop recommended extending the energy range for electrons to below the lower energy limit of the GOES N-Q satellites of 30 keV. The main phenomenon driving this recommendation was differential charging of satellite surfaces (Fennell; Mandell; Carey)."
  - "The workshop recommended extending the energy range for protons to below the lower energy limit of the GOES N-Q satellites of 30 keV. The phenomena driving this recommendation were radiation dose to surfaces, surface damage [Bodeau; Fennell] and source populations for the ring current [Carey; Sibeck]."

MPS-LO Energy Channels

Electrons	Energy, R (keV)	Energy, L (keV)	Ions	Energy, R (keV)	Energy, L (keV)
E15	0.025	0.027	I15	0.030	0.030
E14	0.040	0.044	I14	0.049	0.049
E13	0.066	0.073	I13	0.080	0.081
E12	0.115	0.121	I12	0.130	0.130
E11	0.192	0.199	I11	0.212	0.212
E10	0.316	0.339	I10	0.346	0.346
E9	0.527	0.544	I9	0.564	0.566
E8	0.888	0.900	I8	0.926	0.926
E7	1.502	1.488	I7	1.514	1.518
E6	2.439	2.464	I6	2.490	2.494
E5	4.043	4.079	I5	4.094	4.094
E4	6.732	6.767	I4	6.588	6.737
E3	11.20	11.21	I3	11.30	11.30
E2	18.59	18.62	I2	18.20	18.20
E1	30.81	30.81	I1	30.00	30.00

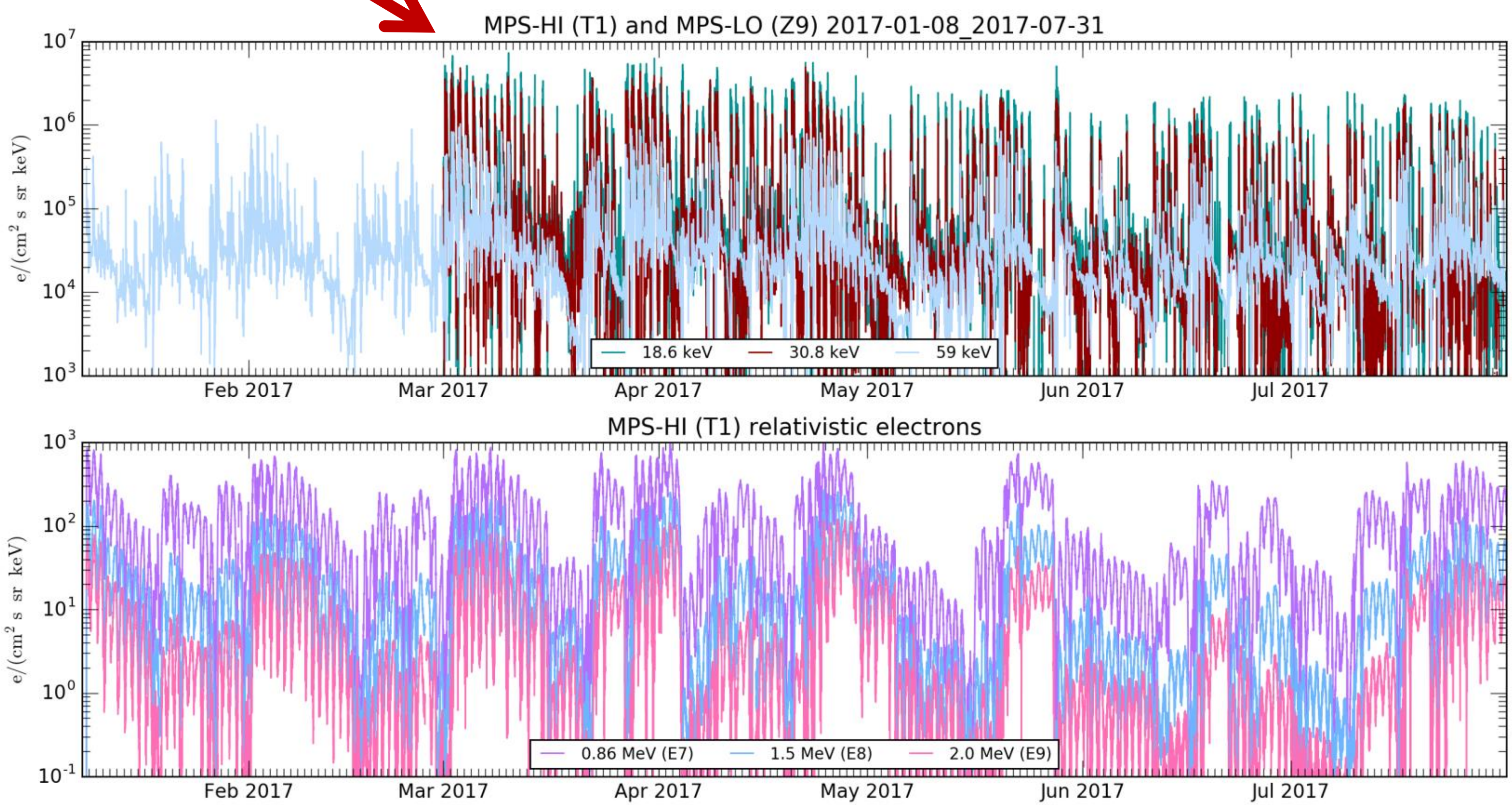
L and R analyzer energies are separately characterized

Analyzer parameter: $\Delta E/E = 0.049$

MPS-LO and MPS-HI 18-60 keV Electron Fluxes, 08 January – 31 July 2017

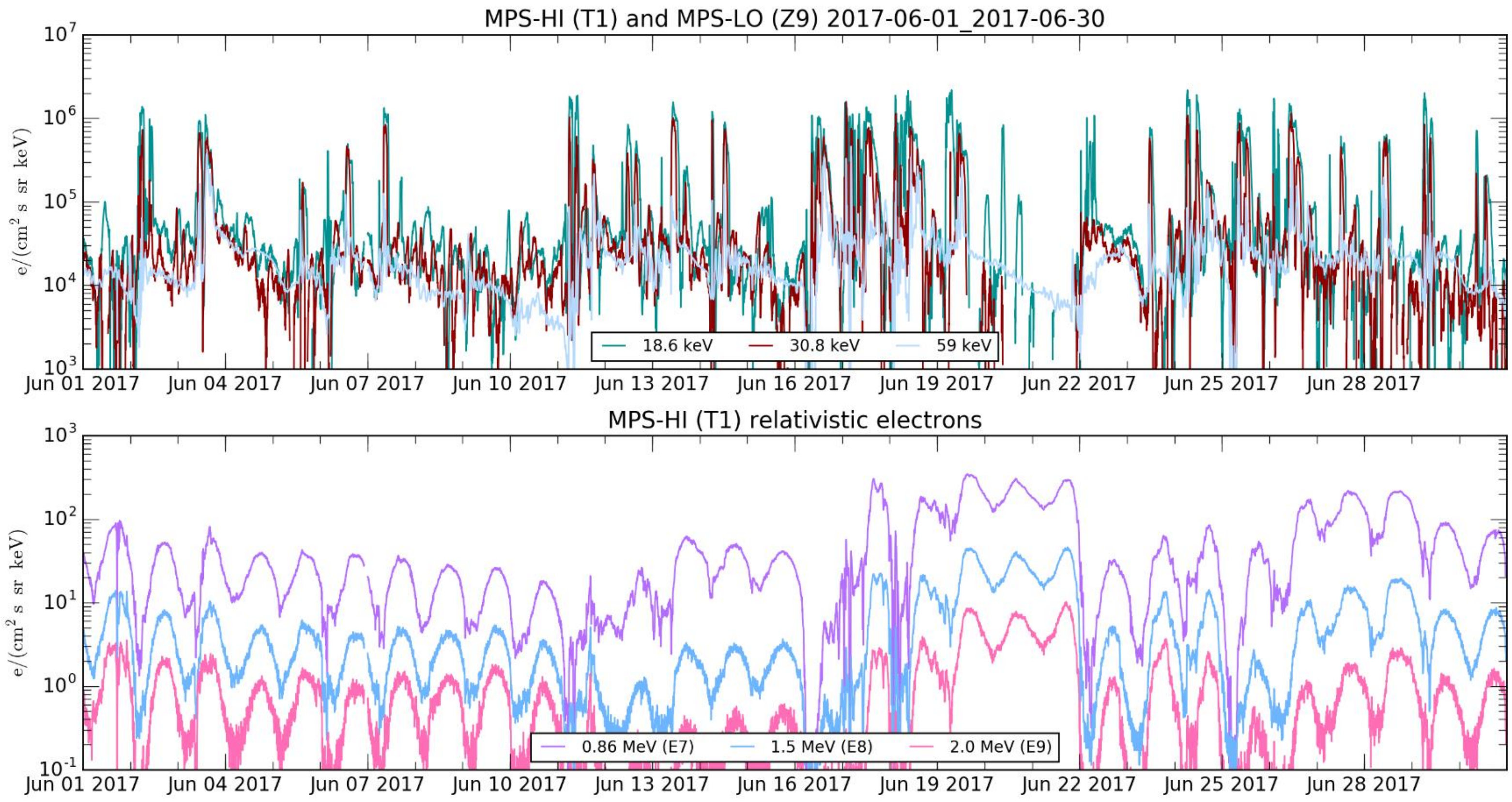
MCP HV adjusted 01 March

Telescope 1 and Zone 9 are ~coaligned



MPS-LO and MPS-HI 18-60 keV Electron Fluxes, 01-30 June 2017

Telescope 1 and Zone 9 are ~coaligned



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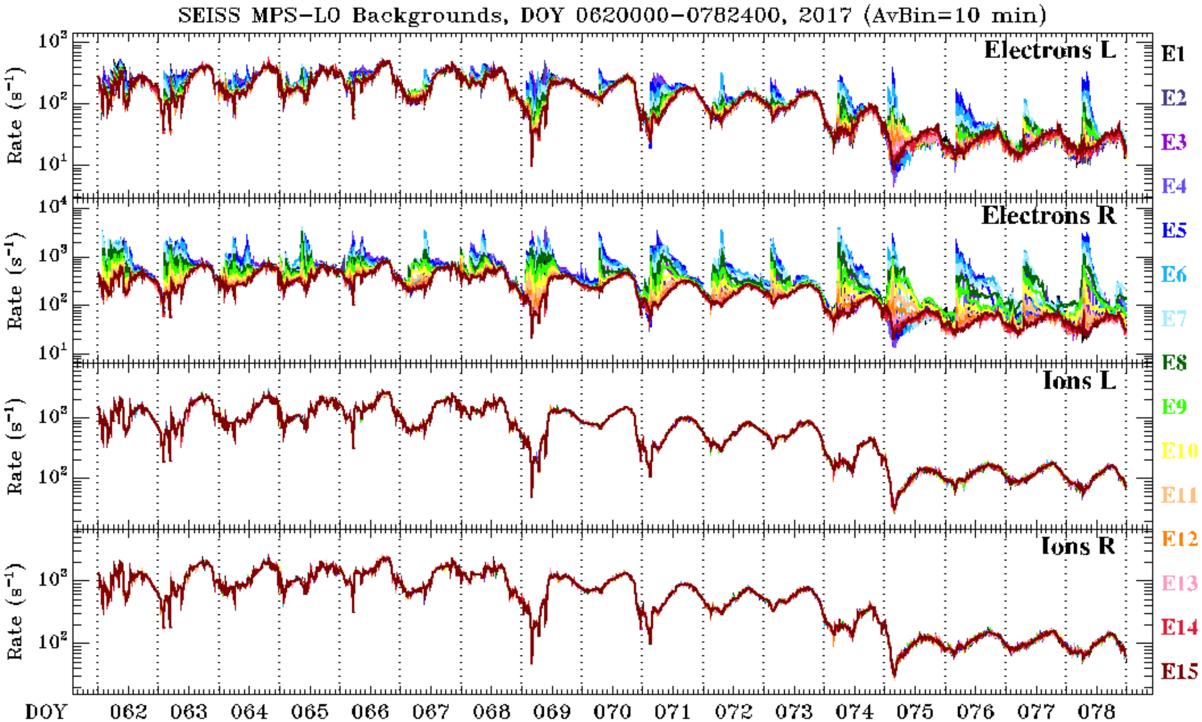
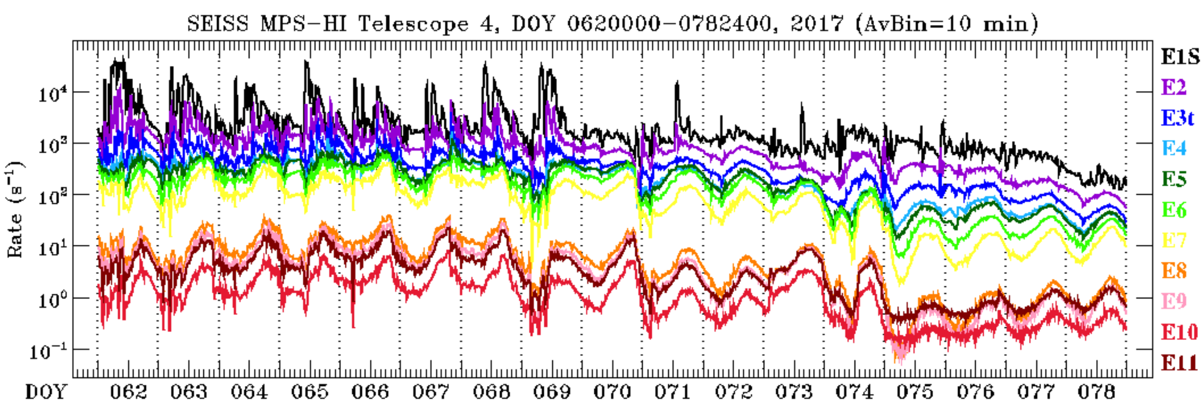
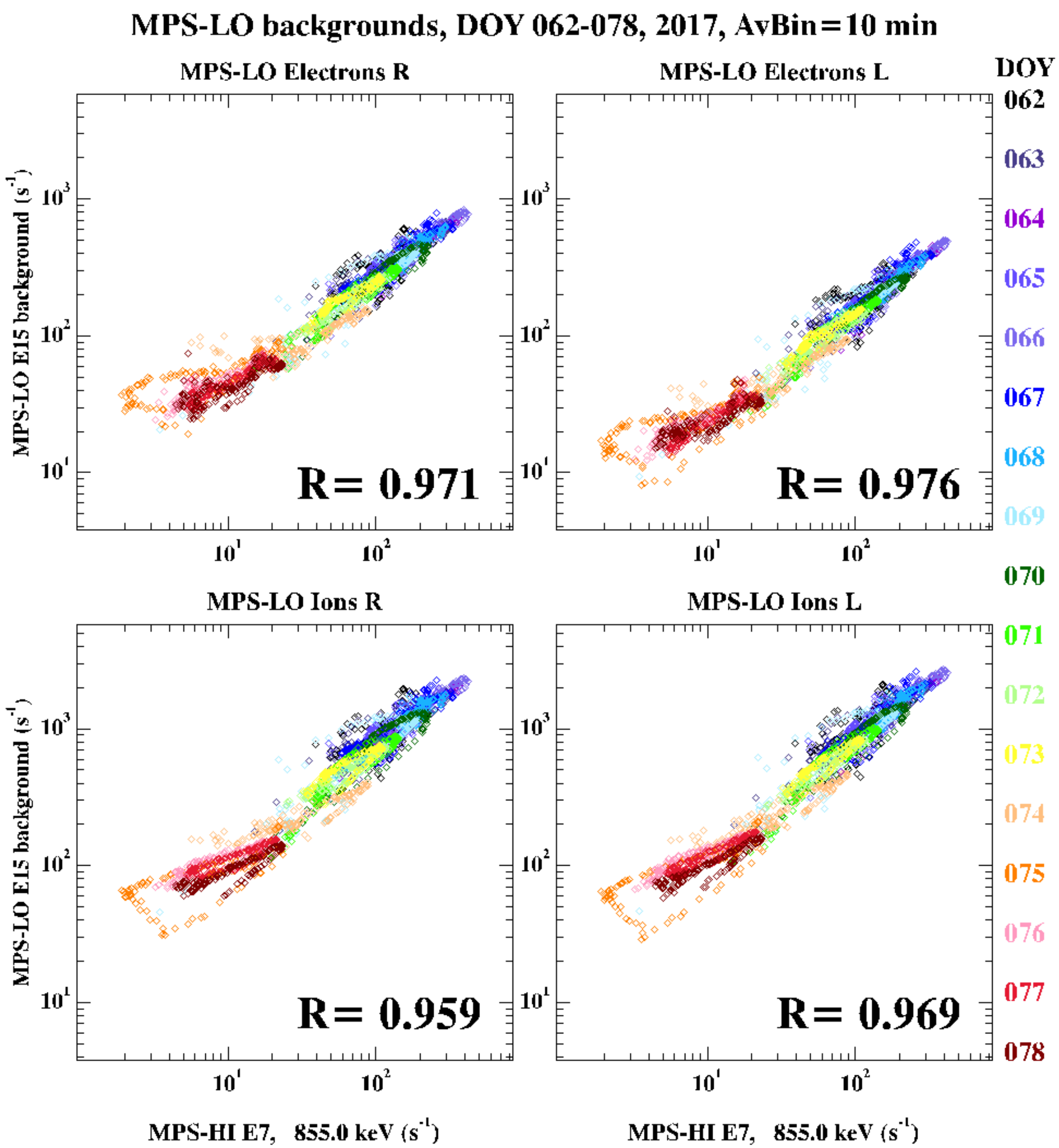
SEISS MPS-LO Backgrounds





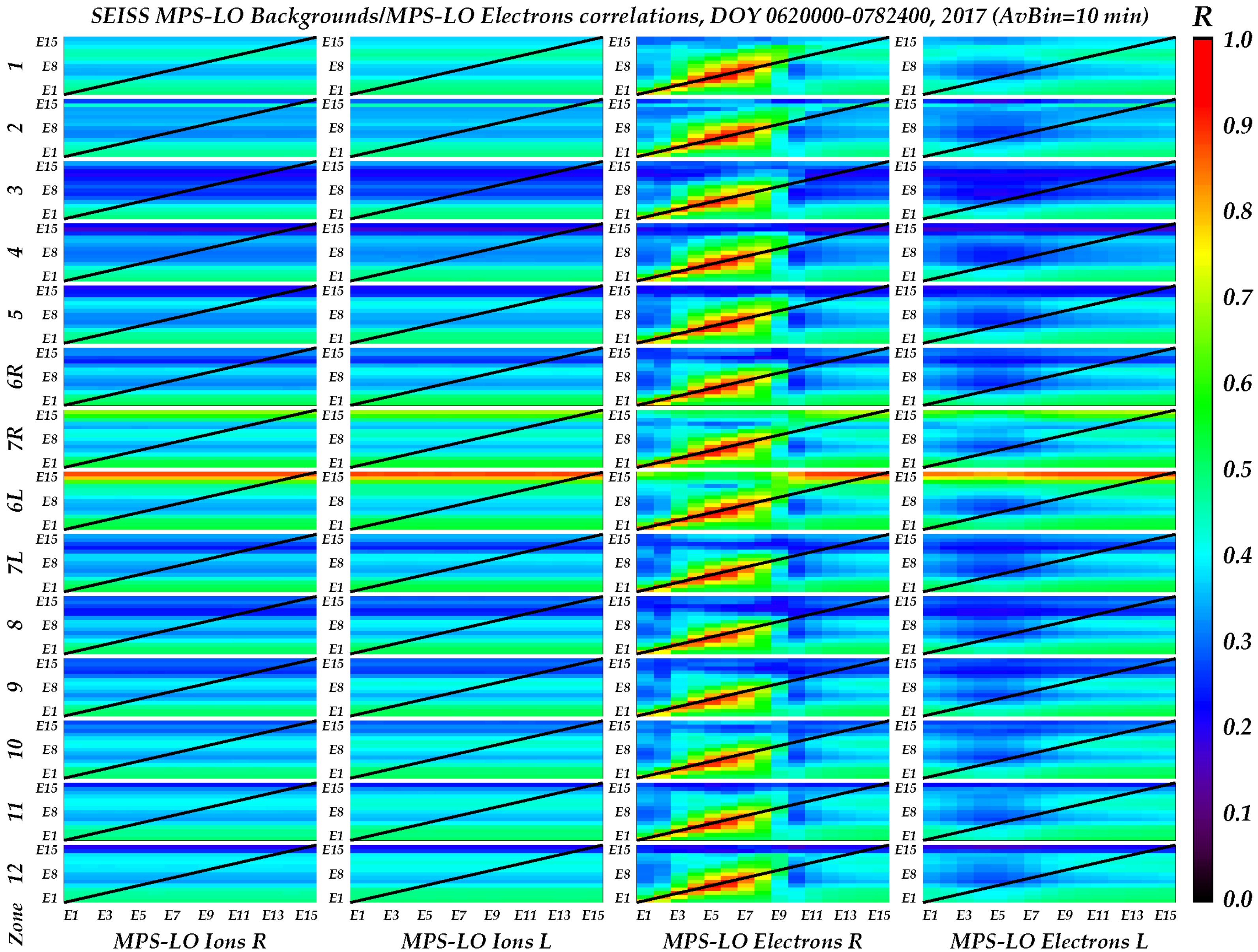
- 4 background zones: Electrons L, Electrons R, Ions L, Ions R
- 15 energy channels: E1 at 30 keV, E15 at 30 eV
- Plotted for days 062 to 078 of 2017
- Plotted along all the MPS-HI electron channels (E1S-E11)
- Similar daily correlation between MPS-LO backgrounds and MPS-HI, at least for the ion and low-energy electron MPS-LO backgrounds

SEISS MPS-LO backgrounds: Penetrating Radiation

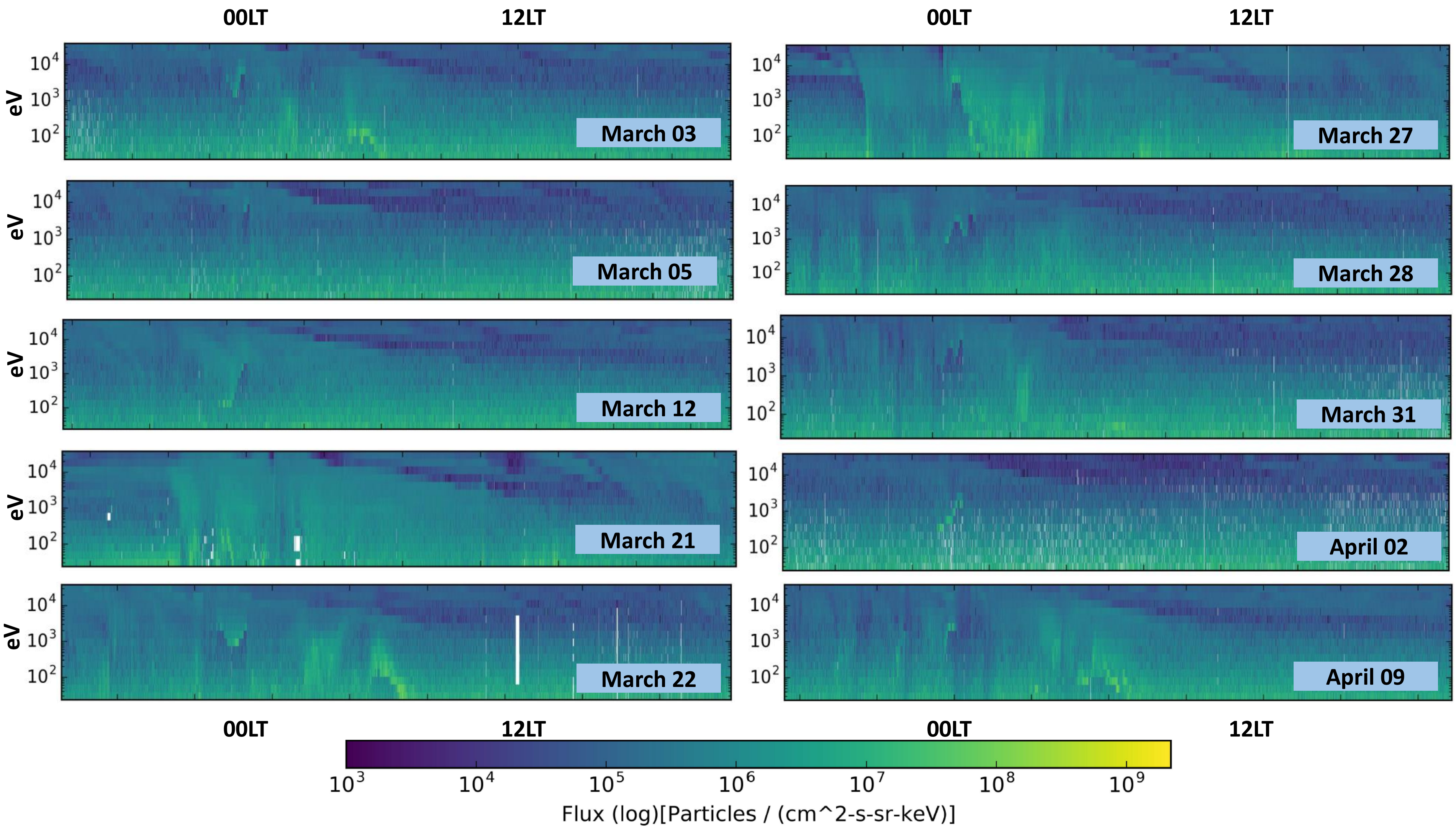


- 4 background zones: Electrons L, Electrons R, Ions L, Ions R
- Scatter plot of MPS-LO lowest energy channel (E15 at 30 eV) and MPS-HI channel E7
- Color coded days 062 to 078 of 2017
- R is the linear Pearson Correlation Coefficient, measure of a linear relation between the two plotted variables (1-linear correlation, 0-no linear correlation)

SEISS MPS-LO Backgrounds: Coupling



Ion Line Examples Observed in MPS-LO Fluxes (Zone 4)



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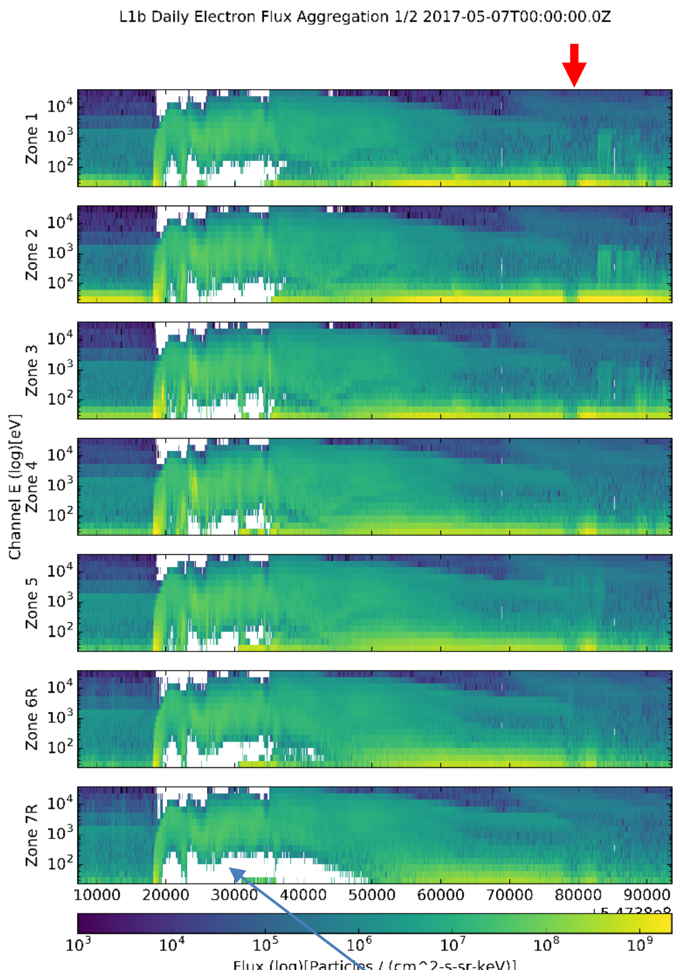
Ion Line Occurrence in MPS-LO Data

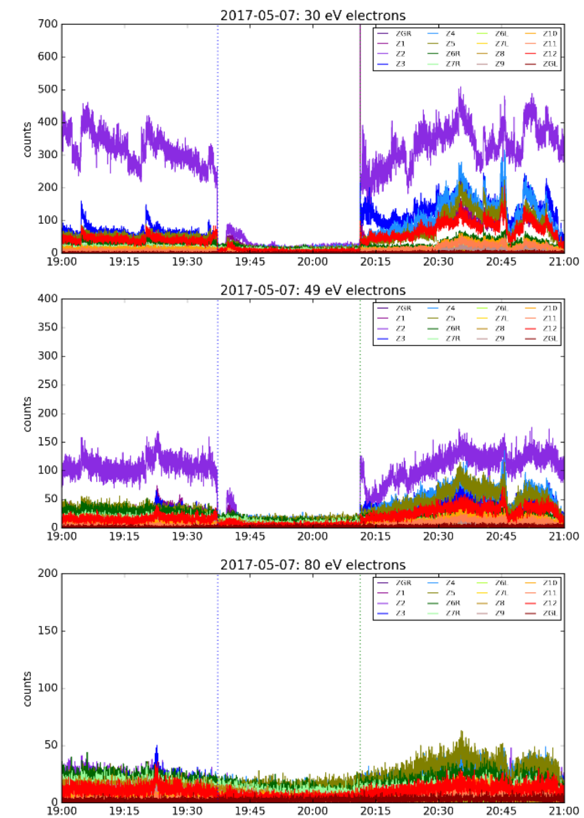
- Visually inspected E-t spectrograms from 01 March – 31 May 2017
  - 42 days when s/c in umbra (01 March – 11 April) – 2 days w/o data = 40 cases
- Looked for occurrences of ion lines
  - Noted whether any part of the ion line exceeded 1 keV
  - Compared their occurrence times to umbra start/finish times
- Results:
  - In 40 eclipse days observed (01 March – 11 April):
    - >1 keV ion line in 18 cases during eclipse
      - Most negative potential observed ~9 kV (31 March)
    - Ion line <1 keV in 3 cases during eclipse
    - Ion line vanishes when s/c exits eclipse
    - 5 clear ion lines outside eclipse, only 1 above 1 keV
  - In 50 non-eclipse days examined (12 April – 31 May):
    - No clear ion lines >1 keV
    - Two clear ion lines <1 keV

Initial conclusion: on GOES-16, ion lines in MPS-LO data are predominantly an eclipse phenomenon

Effect of Arcjet Firings on MPS-LO Data

- GOES-R uses arcjets for north-south stationkeeping
  - Electric arc sustained inside hydrazine rocket engine for increased exhaust velocity, reduced fuel consumption
- Distinct, repeatable suppression of the electron counts in the lowest 2-3 energy channels
- No clear signature in ion channels

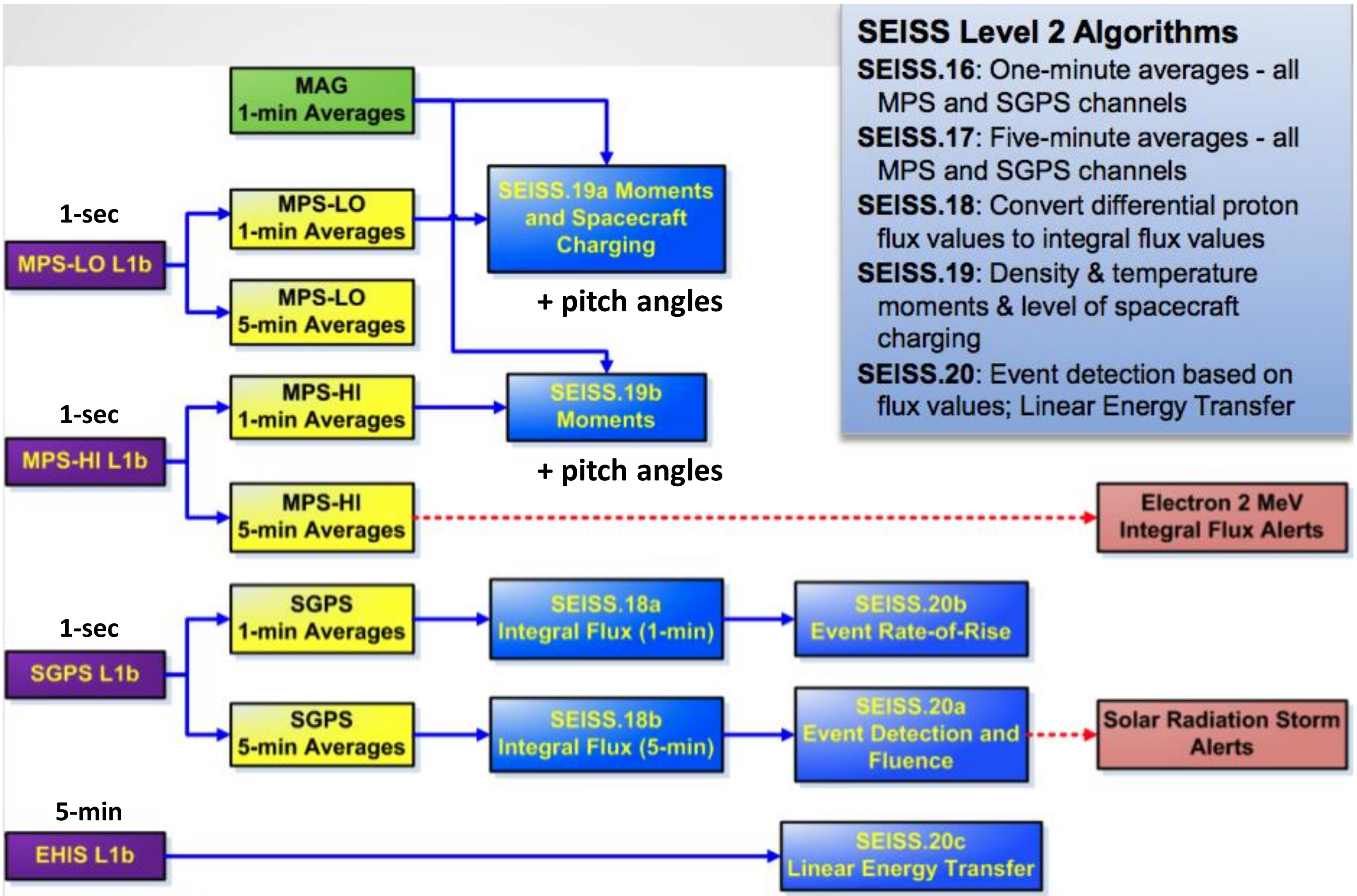




(White blotches on spectrograms due to overcorrection by current background removal algorithm)

SEISS Level 1 and 2 Data Products

Level 2 Initial Operational Capability (IOC): September 2018



Summary

- GOES-16 SEISS Magnetospheric Particle Sensors are generally operating as expected
- Technical issues in work:
  - MPS-HI background removal over all energetic proton conditions (not yet fully tested – 14 July 2017 SEP event too weak to contaminate)
  - MPS-LO background removal, esp. energy-dependent coupling
  - Understanding charging behavior observed by MPS-LO and refinement of automatic determination of s/c potential
  - Implementation of Level 2 moments algorithms in real-time processing system