Deriving proper electron characteristics in the solar wind from Solar Orbiter observations

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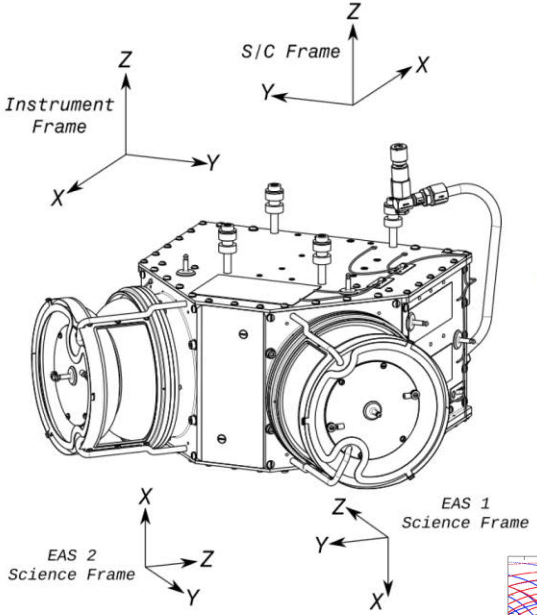
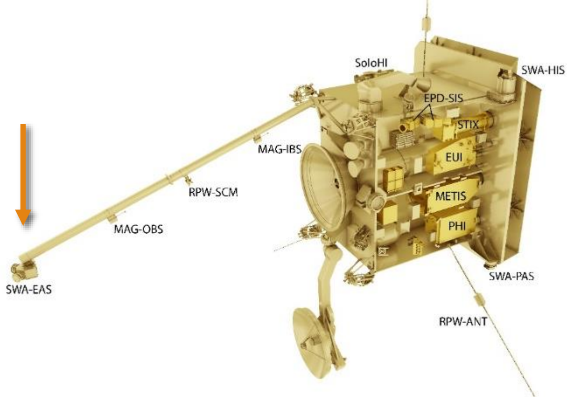
EGU General Assembly 2022, ST1.8 – Open Session on the Sun and Heliosphere

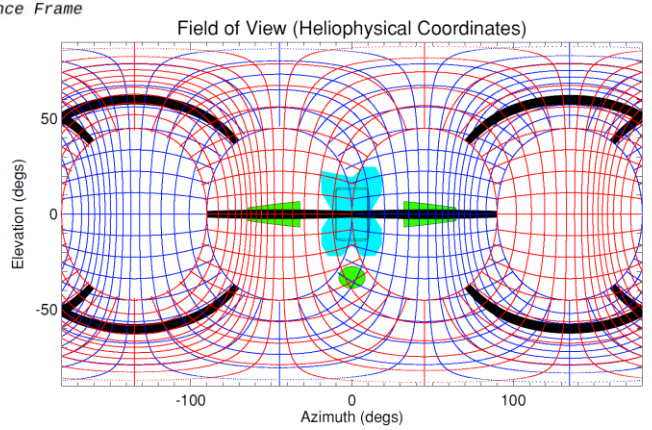
Vienna, Monday, 23 May 2022

EAS instrument

- Electron Analyser Sensor (EAS) is part of Solar Wind Analyser (SWA) suit on Solar Orbiter S/C
- Two top-hat electrostatic analysers
  - Energy coverage up to ~ 5 keV in 64 steps
  - Full 2π azimuth coverage in 32 uniform steps
  - $\pm \pi/4$ coverage in elevation with 16 non-uniform steps
- Combined EAS1/EAS2 4π FOV (incl. partial blockages)
- Full 3D VDF in normal operational mode every 10/100 s from both EAS sensors
- See Owen et al. (2020) for complete information (https://doi.org/10.1051/0004-6361/201937259)

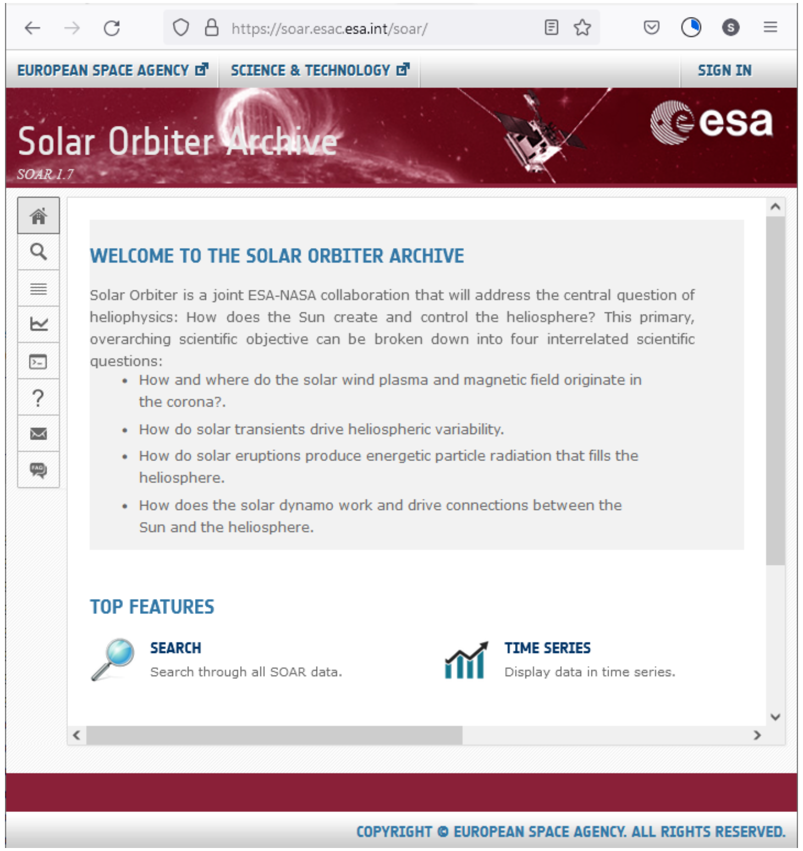






EAS data

- Solar Orbiter Archive (SOAR)
  https://soar.esac.esa.int/soar/
- Binary files in Common Data Format (CDF)
- Level 1 data
  - Raw instrument counts
  - EAS sensors reference frames
- Level 2 data
  - Conversion of raw counts into physical units by on-ground derived geometric factors
  - EAS sensors reference frames
  - PSD – phase space densities
  - DNF – differential number flux
  - DEF – differential energy flux
- S/C ancillary data – SPICE kernels



EAS electron moments - computation

Moments definitions

Density

$$n = \int_{R^3} f(\vec{v})\, d\vec{v}$$

Bulk speed

$$\vec{v}_b = \frac{1}{n} \int_{R^3} \vec{v} f(\vec{v})\, d\vec{v}$$

Temperature

$$T = \frac{m}{3 k_B n} \int_{R^3} |\vec{v} - \vec{v}_b|^2 f(\vec{v})\, d\vec{v}$$

Heat flux

$$\vec{Q} = \frac{m}{2} \int_{R^3} (\vec{v} - \vec{v}_b) |\vec{v} - \vec{v}_b|^2 f(\vec{v})\, d\vec{v}$$

EAS measurements

$$\boldsymbol{f_{i,j,k} = f(E_i, \varphi_j, \theta_k)}$$

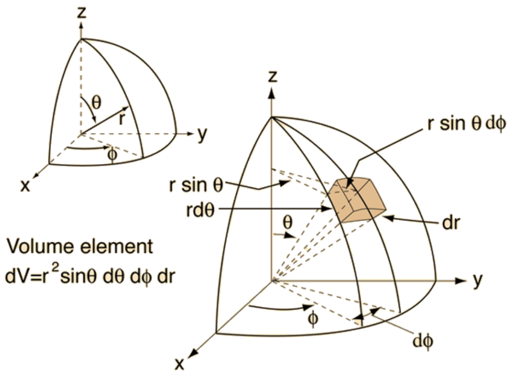
E_i - *energy bin*

φ_j - *azimuth bin*

θ_k - *elevation bin*

$$v_{i,j,k} = v(E_i, \varphi_j, \theta_k)$$

$$V_{i,j,k} = v_i^2 \sin\theta_k d\theta_k d\varphi_j d\, v_i$$



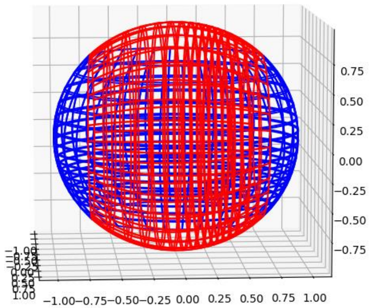
Direct numerical integration

$$\boldsymbol{m_{n,EASX} = \sum_{i,j,k} v_{i,j,k}^n w_{j,k} f_{i,j,k} V_{i,j,k}}$$

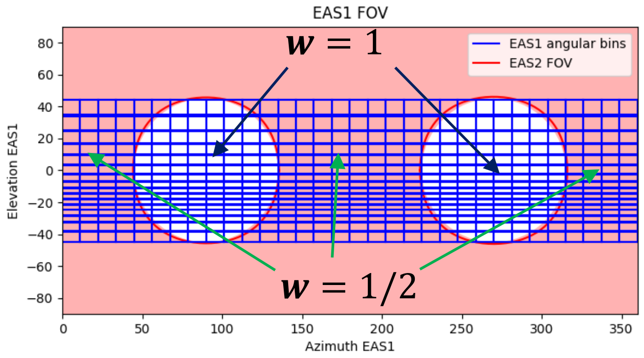
$$\boldsymbol{m_{n,EAS} = m_{n,EAS1} + m_{n,EAS2}}$$

(+) fast, no need to impose any eVDF model

(–) noise, instrumental effects

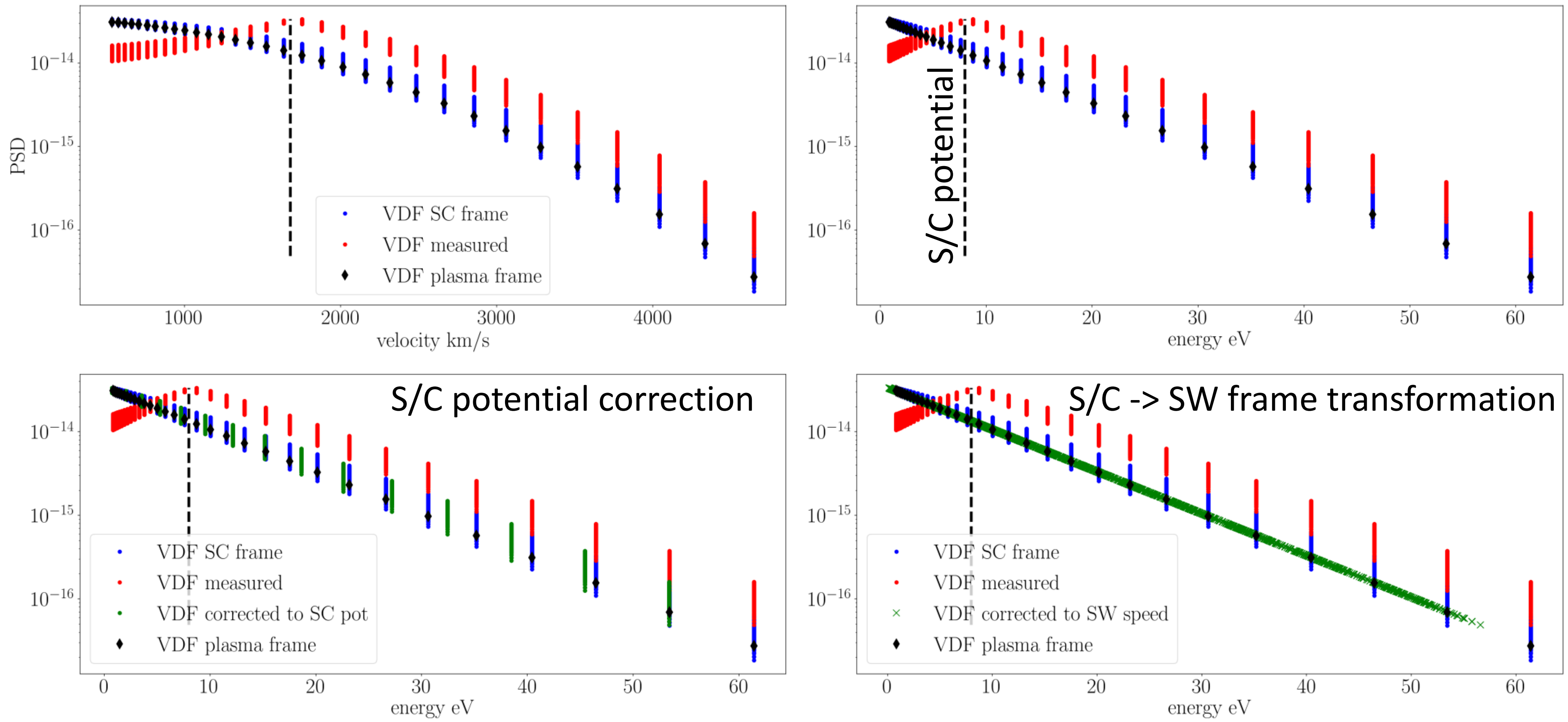


EAS1/2 4π FOV



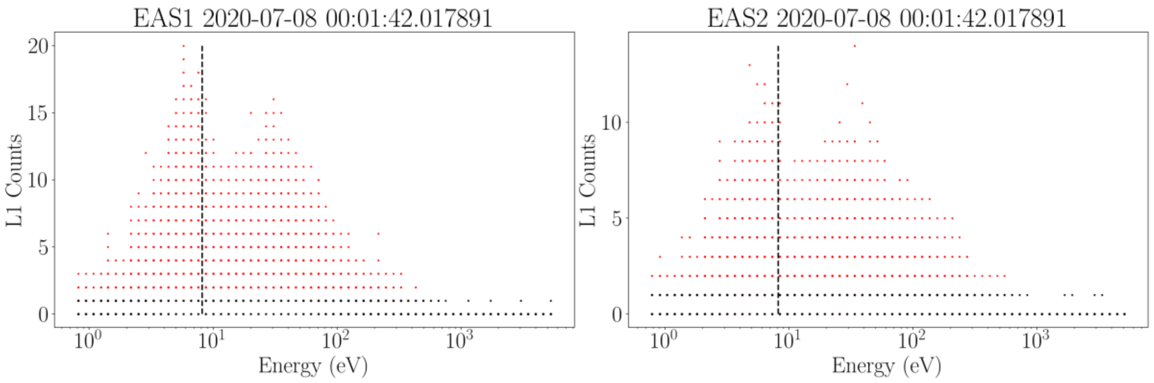
VDF corrections I

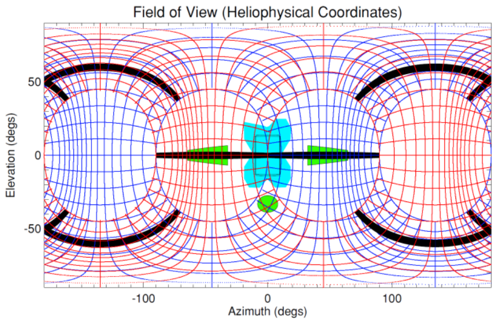
Virtual EAS1 measurement
Maxwellian VDF
SW bulk speed 300 km/s
S/C potential 8 V

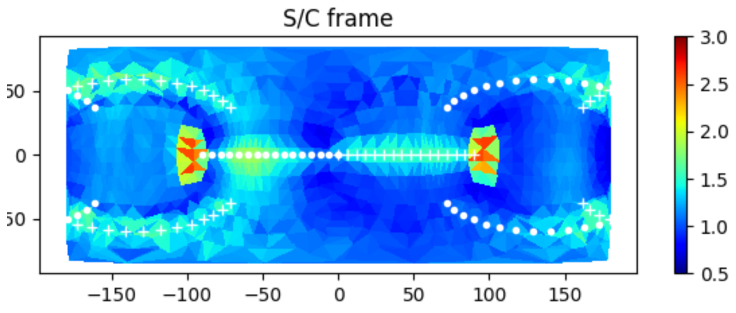


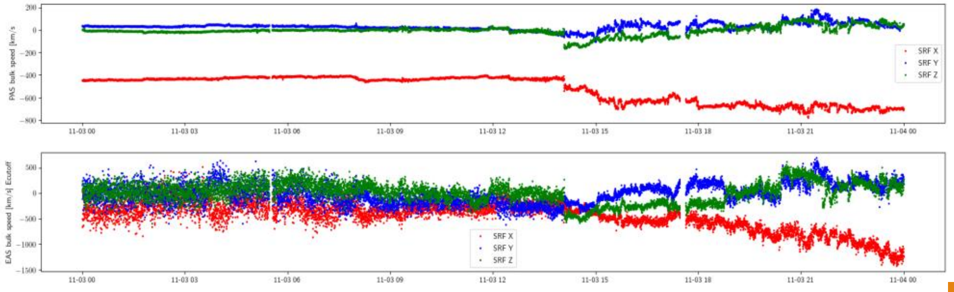
VDF corrections II – instrumental effects

- Photoelectrons or secondary electrons contamination
  - Low energy bins (up to ~ 10 eV) polluted/dominated by cold electrons of S/C origin
- FOV blockage
  - S/C body
  - Solar panels
  - EAS mechanical parts (E box, pillars)
- Wake effects
  - Ram (EAS1) vs wake (EAS2) differences due to S/C speed
- Instrument design
  - EAS1 vs EAS2 cross calibration (different sensitivity)
  - Energy sweep effects (effective mean bin energy)
- All of the above is currently **work in progress of the EAS instrument team**









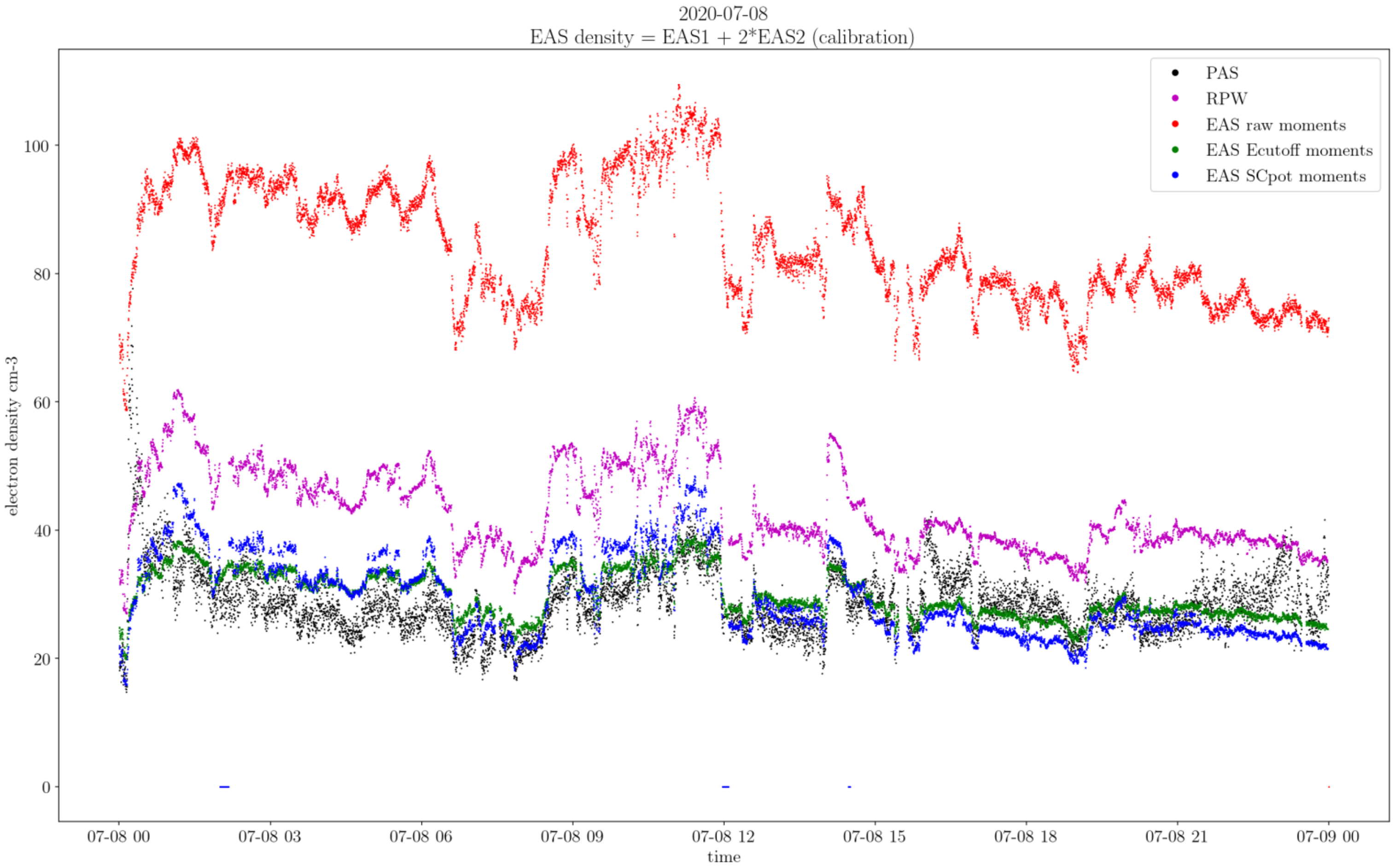
EAS moments - density

EAS uncorrected moments

RPW electron density

EAS corrected moments

PAS proton density



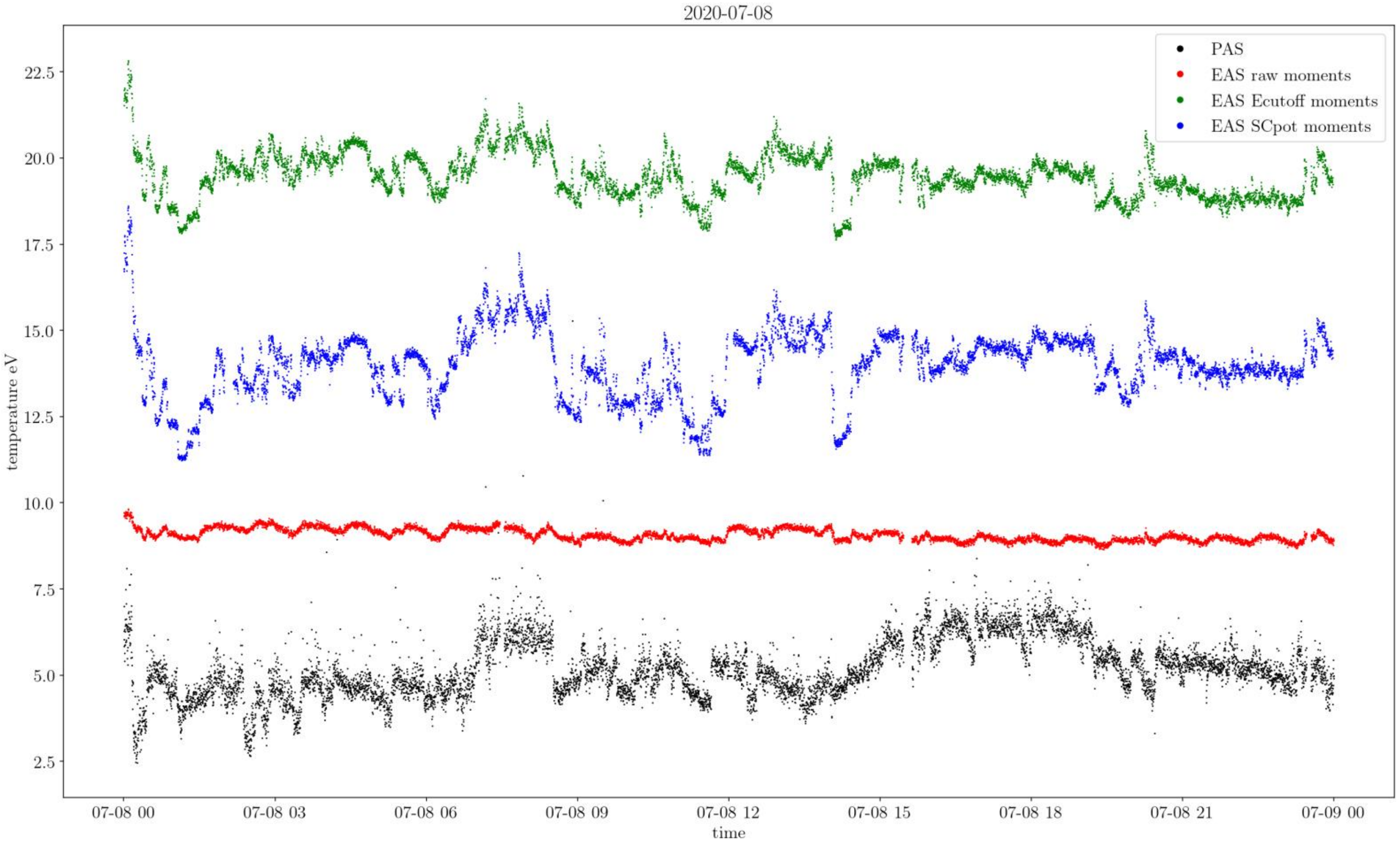
EAS moments - temperature

EAS uncorrected moments
E > 10eV

EAS corrected moments

EAS uncorrected moments

PAS proton temperature



Conclusions

- Large EAS dataset available at SOAR with number of events of interest
- Preliminary EAS moments show good correlation with other plasma measurements (PAS, RPW)
- For any scientific analysis of L2 data (un)known artificial effects have to be still considered for correct data interpretation
- Level 3 data planned to be supplied by the EAS team to the SOAR once the most important issues will be solved
  - EAS1/EAS2 combined 3D VDF
  - EAS1/EAS2 combined 2D PAD
  - VDF moments (n, T, q)

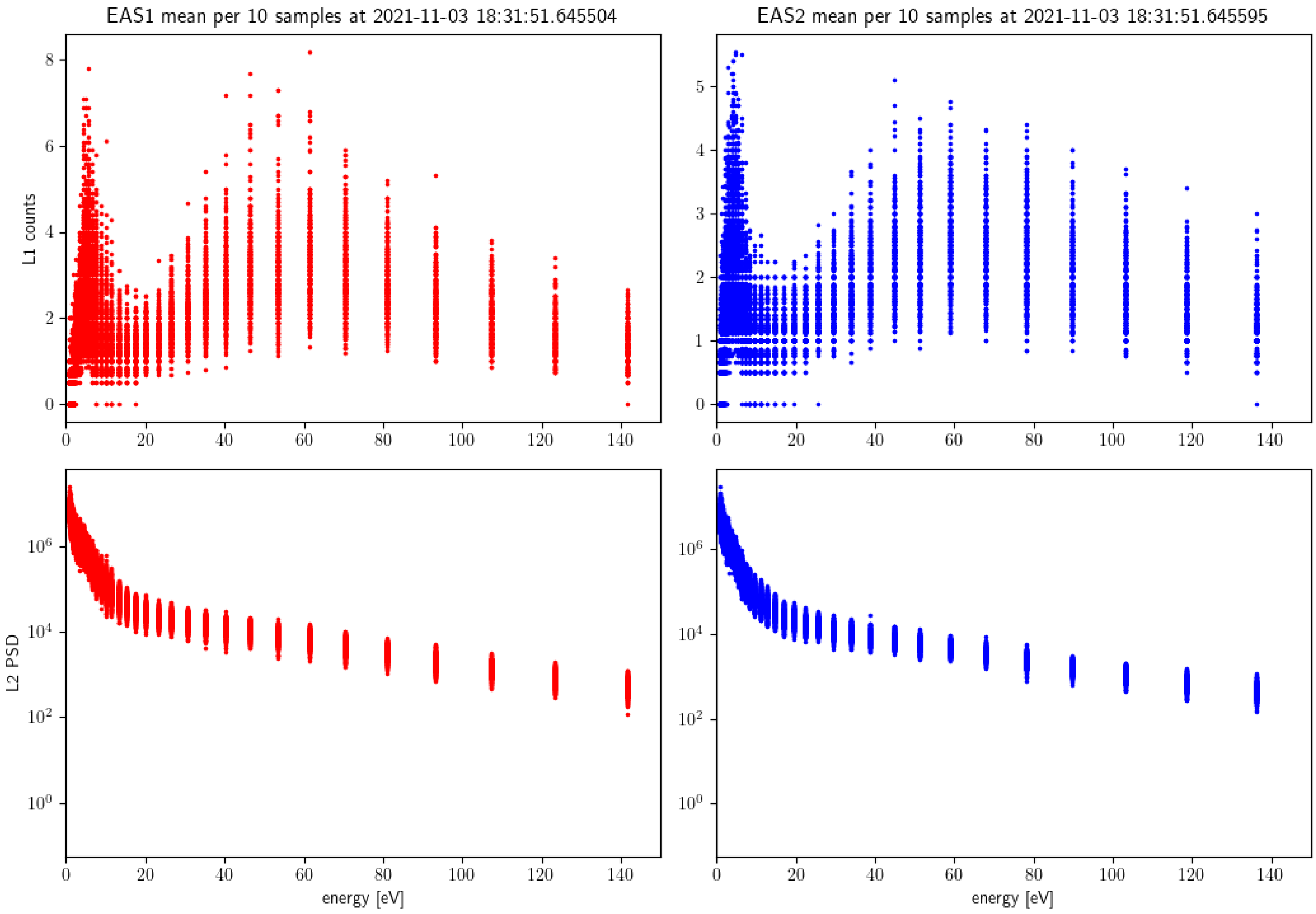
To help further improve the EAS data set

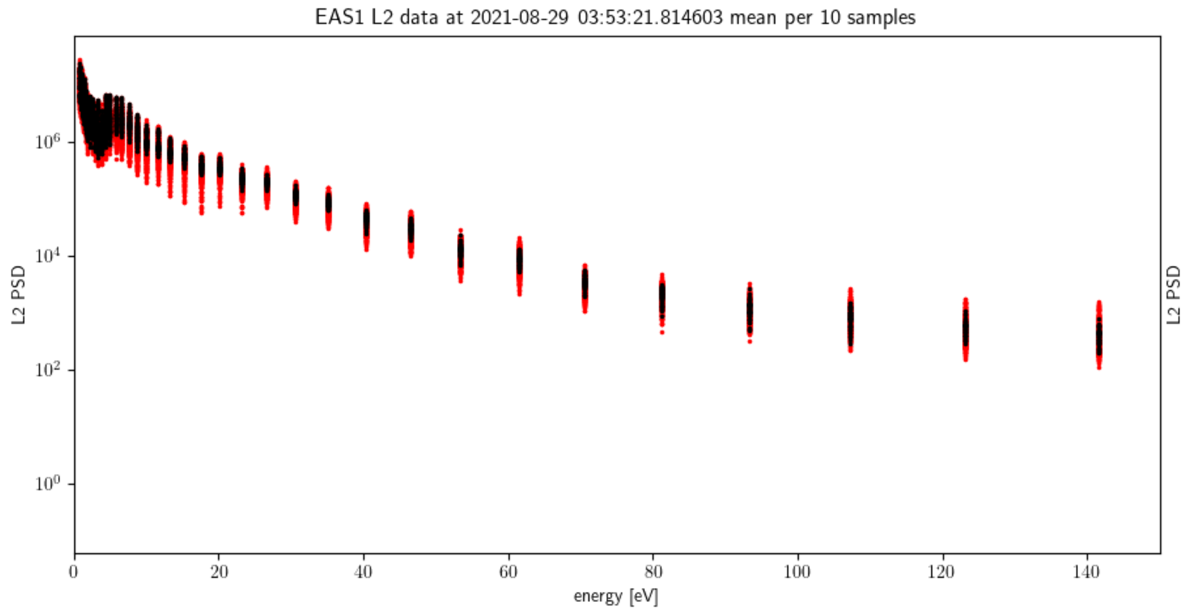
USE EAS DATA!

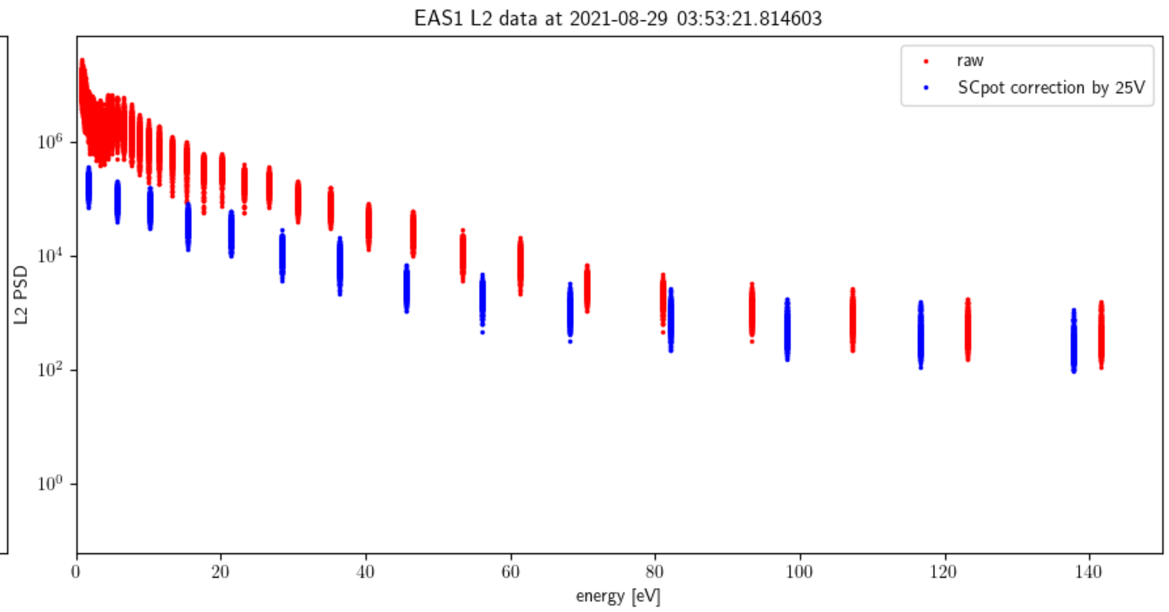
GIVE YOUR FEEDBACK TO THE EAS TEAM!

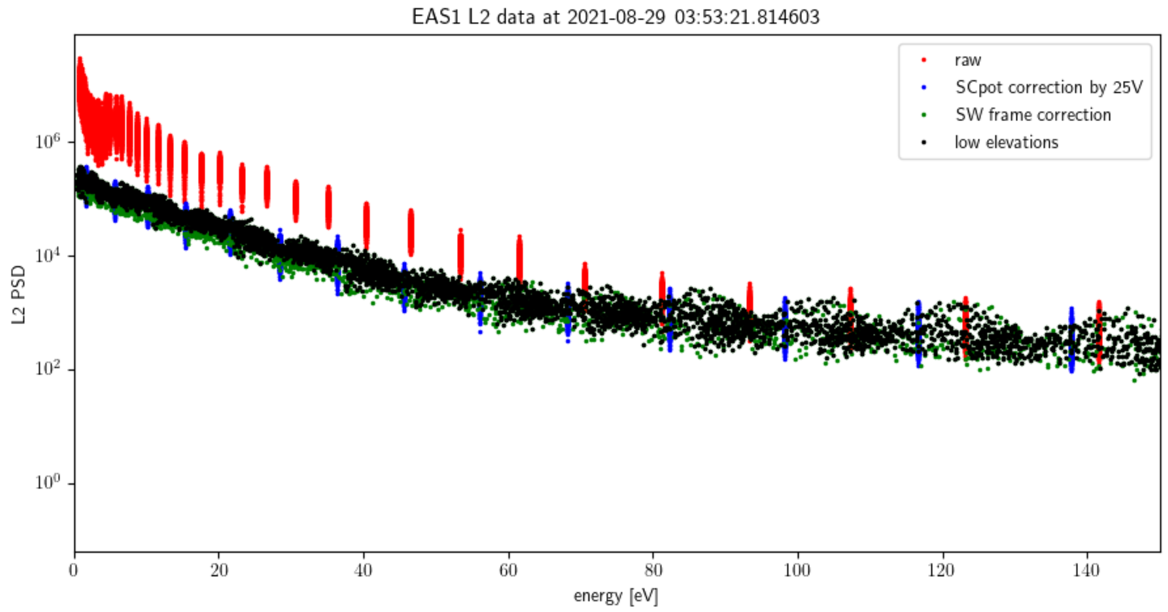
(SWA PI – C. J. Owen, MSSL, UCL)

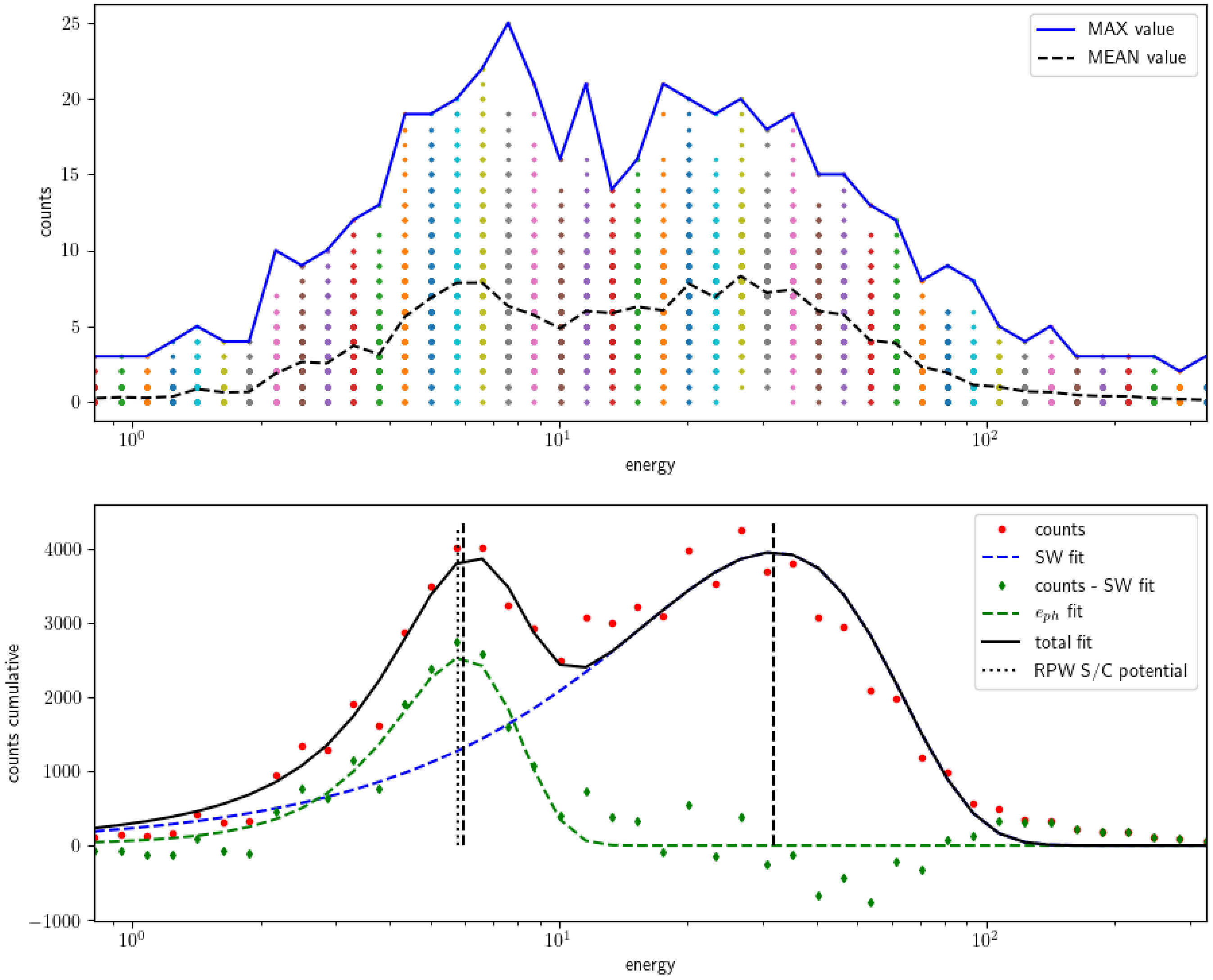
Extra slides

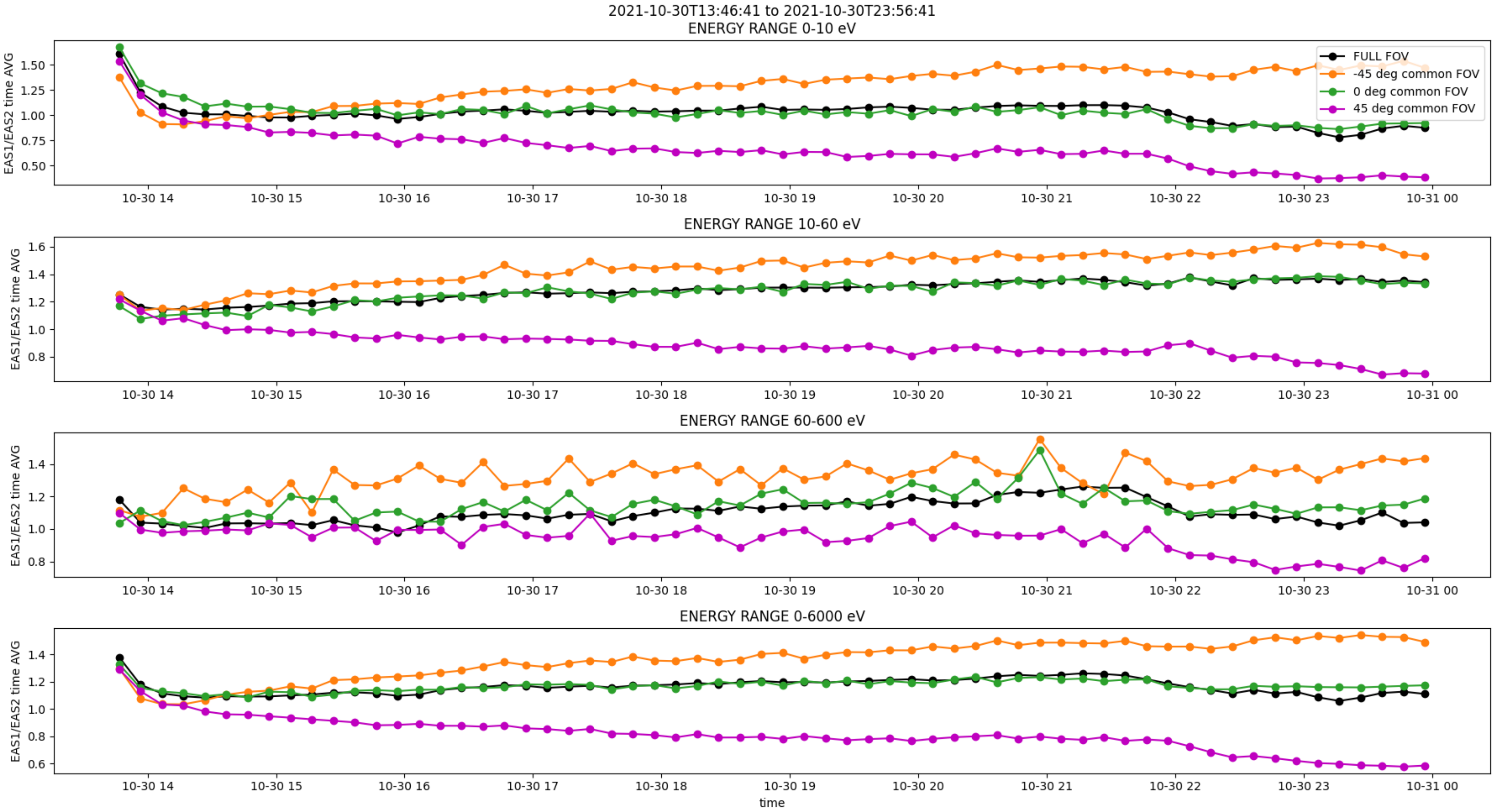

EAS1 mean per 10 samples at 2021-11-03 18:31:51.645504
EAS2 mean per 10 samples at 2021-11-03 18:31:51.645595
L1 counts
L2 PSD
energy [eV]
energy [eV]


EAS1 L2 data at 2021-08-29 03:53:21.814603 mean per 10 samples
L2 PSD
energy [eV]


EAS1 L2 data at 2021-08-29 03:53:21.814603
raw
SCpot correction by 25V
L2 PSD
energy [eV]


EAS1 L2 data at 2021-08-29 03:53:21.814603
raw
SCpot correction by 25V
SW frame correction
low elevations
L2 PSD
energy [eV]


MAX value
MEAN value
counts
energy
counts
SW fit
counts - SW fit
e_{ph} fit
total fit
RPW S/C potential
counts cumulative
energy


2021-10-30T13:46:41 to 2021-10-30T23:56:41
ENERGY RANGE 0-10 eV
ENERGY RANGE 10-60 eV
ENERGY RANGE 60-600 eV
ENERGY RANGE 0-6000 eV
EAS1/EAS2 time AVG
FULL FOV
-45 deg common FOV
0 deg common FOV
45 deg common FOV
10-30 14
10-30 15
10-30 16
10-30 17
10-30 18
10-30 19
10-30 20
10-30 21
10-30 22
10-30 23
10-31 00
time