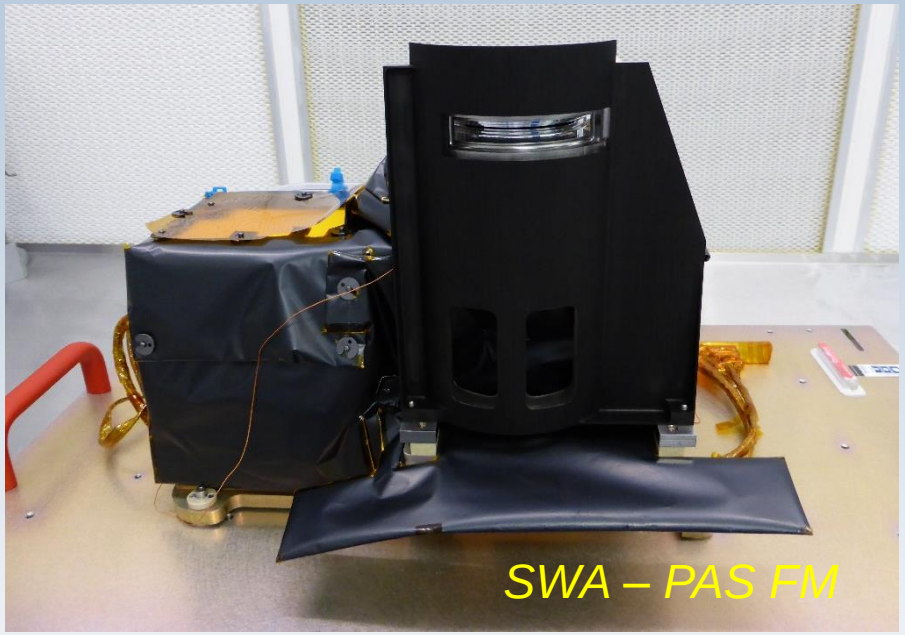
Recent News and Observations from Solar Orbiter SWA

Prof. Chris Owen, UCL/MSSL

Principal Investigator SWA Team on Solar Orbiter

Solar Orbiter - Solar Wind Analysers (SWA)



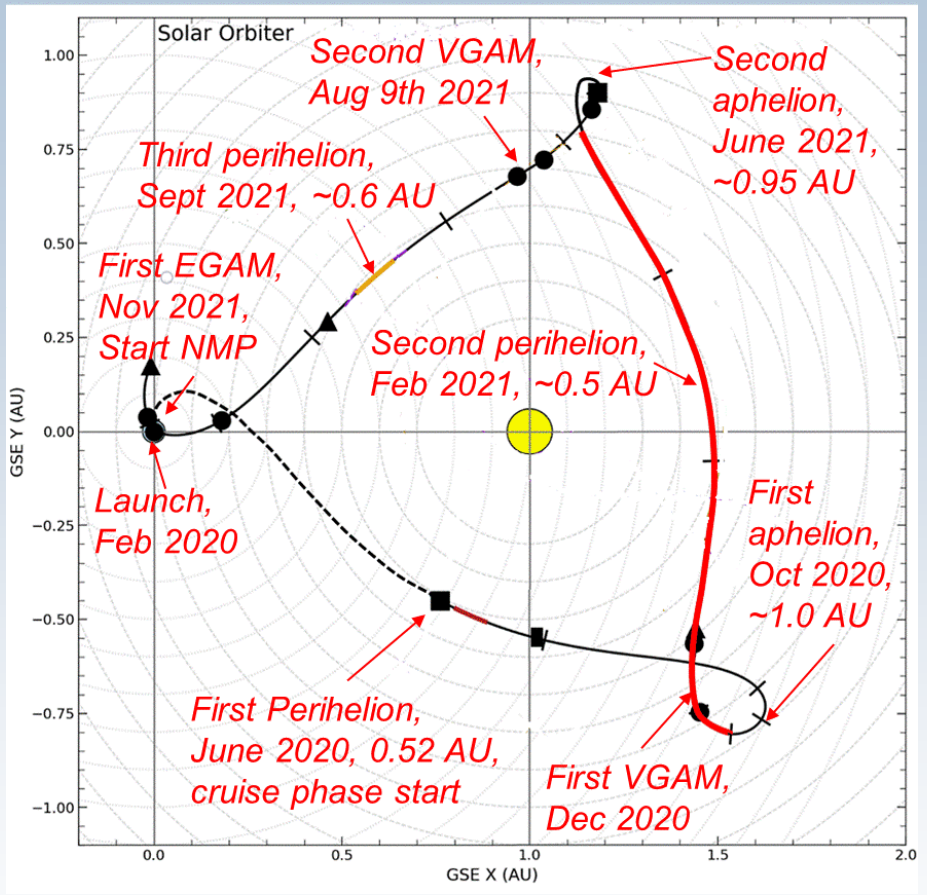
- Electron Analyser System (EAS):
  - Electrons
  - < 5 keV,
  - quasi- 4π sr FoV;
- Build led by UCL/MSSL, UK

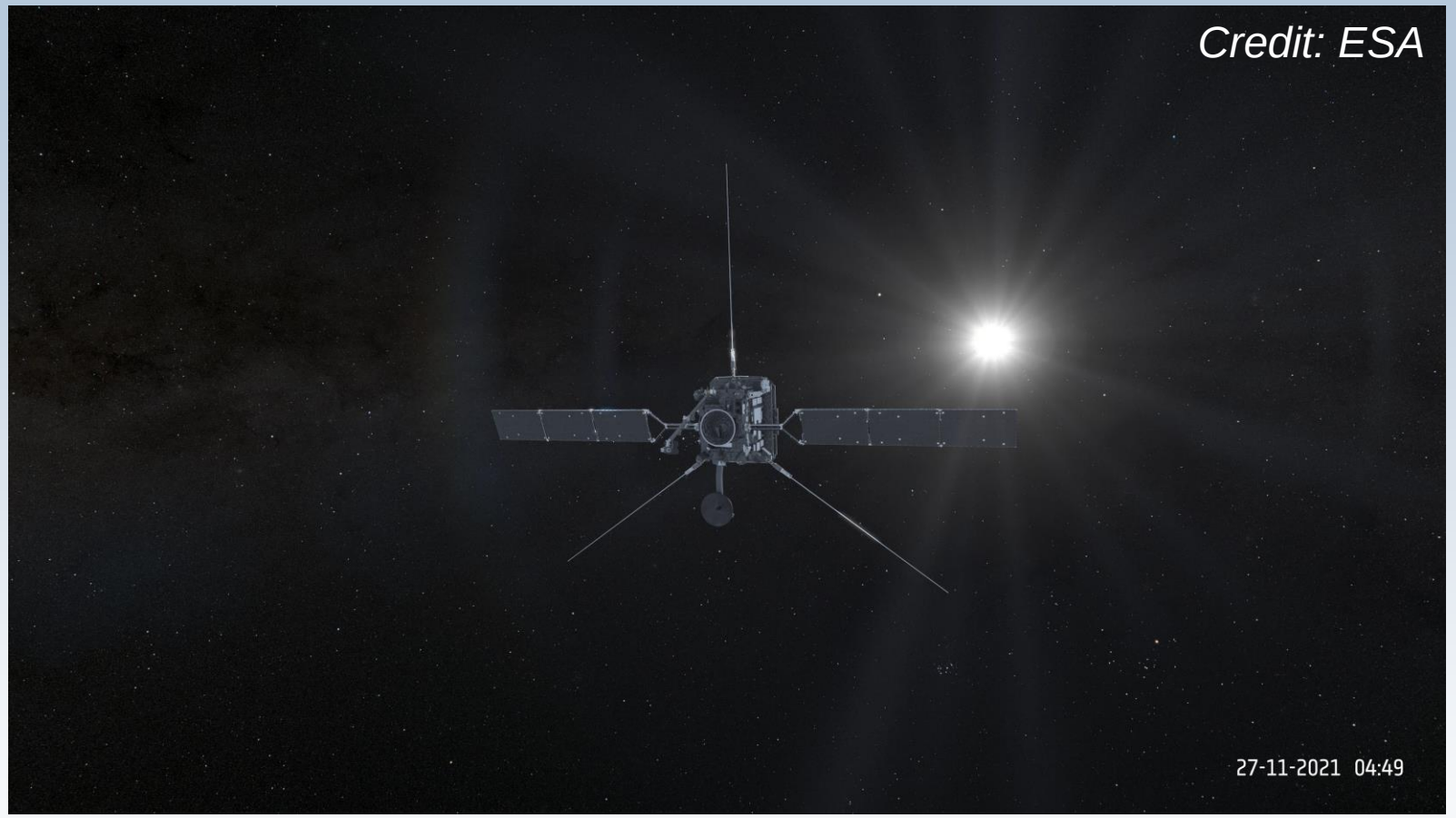
- Proton-Alpha Sensor (PAS):
  - Protons/Alphas,
  - 0.2 - 20 keV/q,
  - 60° × 40° FoV around SW flow direction;
- Build led by IRAP, Toulouse, Fr

- Heavy Ion Sensor (HIS):
  - He – Fe,
  - < 0.5 – 100 keV/q,
  - 96° × 34° FoV centred on SW flow;
- Build led by SWRI (US) and IRAP (Fr)

SWA Operations Status

- Operations
  - All SWA sensors are in operation, with PAS in static mode
  - HK parameters are in good shape and we are returning some excellent science data
  - The redundant DPU has now been in operation for ~ 250 days
- Archiving
  - All SWA data available from 2020 was delivered last year.
    - However, we will shortly redeliver EAS 2020 data with bug fixes, metadata updates and calibration corrections;
  - SWA 2021 (post April restart of operations) EAS & PAS L1 & EAS L2 data have been delivered to SOAR up to 5th September; I HAVE CHECKED THIS IS THERE, CONTRARY TO STATEMENTS YESTERDAY!
  - PAS L2 data reprocessing with new calibrations addressing low-energy counting efficiencies is nearly ready to go;
  - No HIS data is currently being delivered to archive:
    - Quality evaluation very complicated due to SSD noise signatures;
    - Team is devoting time to tuning instrument rather than developing a stop-gap measure;
    - Delivery will begin as soon as team can ensure that data is high quality and well-characterized;

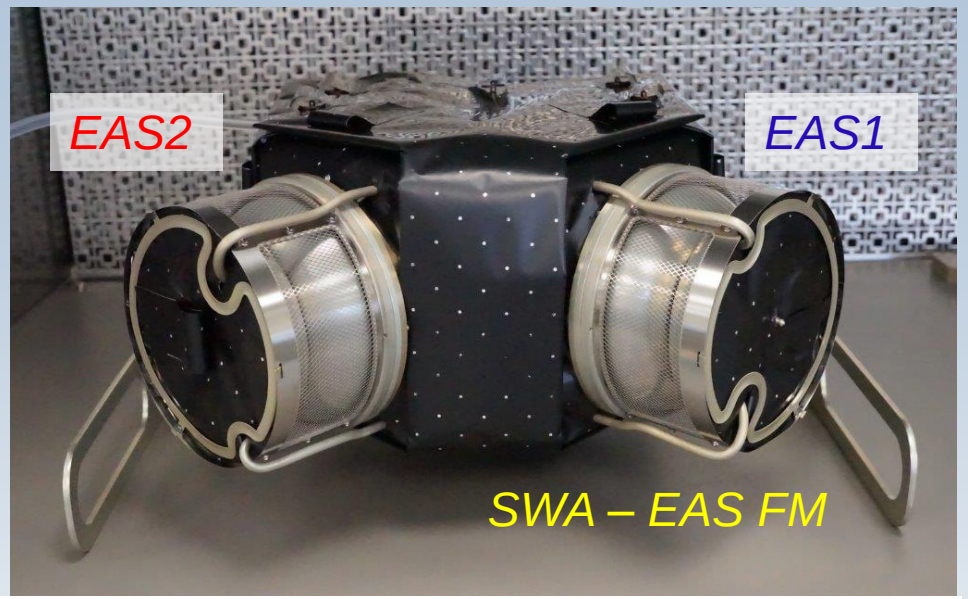


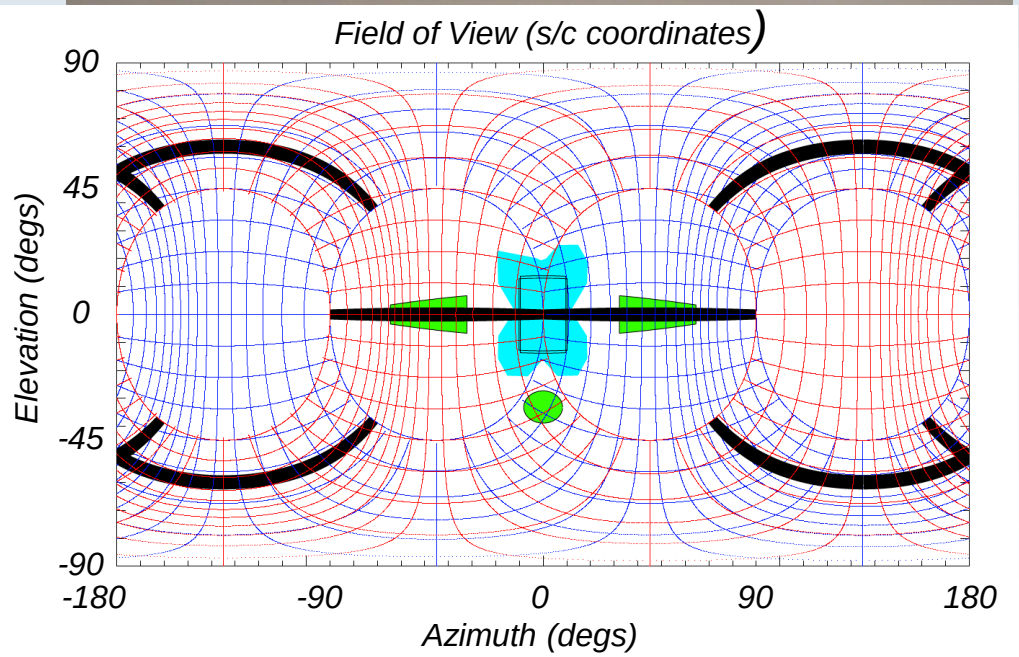


Solar Orbiter ‘nominal’ mission phase began with the Earth swingby on Saturday!

Solar Orbiter – SWA Electron Analyser System (EAS)

- Dual Head Electrostatic Analyser System for < 5 keV electrons;
- Near full sky field of view (with overlaps) except for spacecraft blockages; few degrees angular resolution;
- Full 3D velocity distribution functions (VDFs) at 10 sec or 100 sec resolution;
- Electron ‘moments’ calculated on board in 3 energy and 4 angular ranges at 4 second resolution;
- Burst mode: 2D pitch angle distributions at 0.125 s resolution;
- Trigger function: 5 minutes of full 3D VDFs at 1 sec resolution captured around passage of an interplanetary shock;
- Low-latency single energy angle-angle distribution;
- I will attach some slides describing the cdf’s for these products to the end of this presentation ofr later reference.





Some EAS data availability/quality issues we are working:

- We still have a major issue sorting out the sources (which are highly directional) of photo- and secondary electrons entering our EAS sensor heads and corrupting the low energy measurements and the associated spacecraft charging issues;
- I think this is an area we still need to pursue with the RPW team
- Rob Wicks has been working on this and hope to attend but was unable to come at the last minute, so I think unfortunately we wont make much progress here, but should try to follow up in the coming months….

EAS Post WOL down time

Using the Gain test results we are able to study the effect of the thruster firing on EAS MCPs

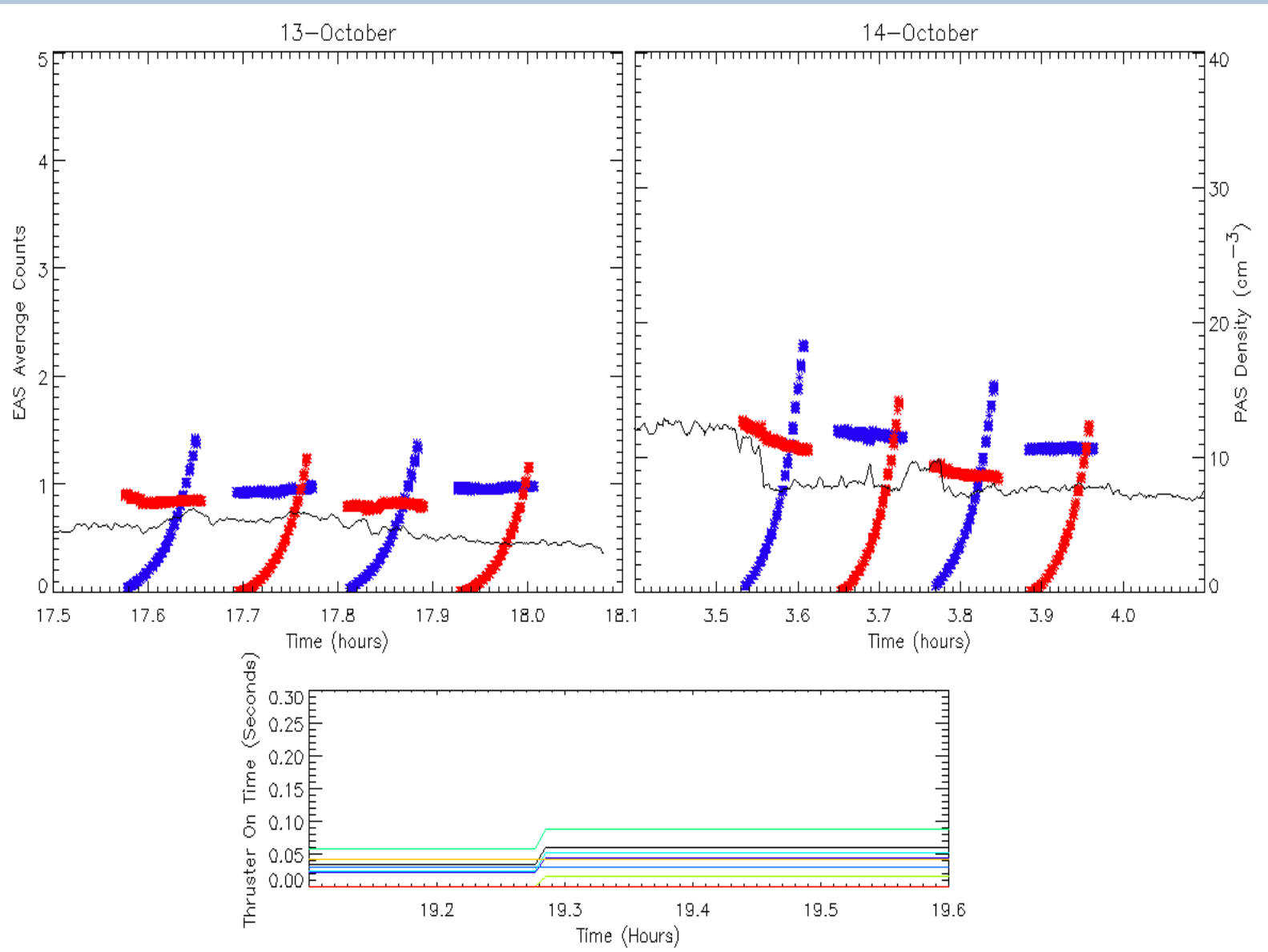
The GTs are performed before the WOL and again after the WOL with some delay time added

These results show the GT pre WOL on the left and post WOL on the right with sweeping MCP voltage on one EAS while the other EAS is at nominal voltage. (Colours depict different EAS)

Also shown in the background is the PAS on-board density to illustrate any plasma activity during the test

The thruster activity is shown on the lower plot

We began the mission with a delay of 8 hours and have gradually decreased this to 4 hours



EAS Sawtooth

Since launch EAS has continuously shown a ‘sawtooth’ effect in its returned counts data

This is seen as horizontal banding in energy seen here particularly at low energies and particularly evident on EAS2

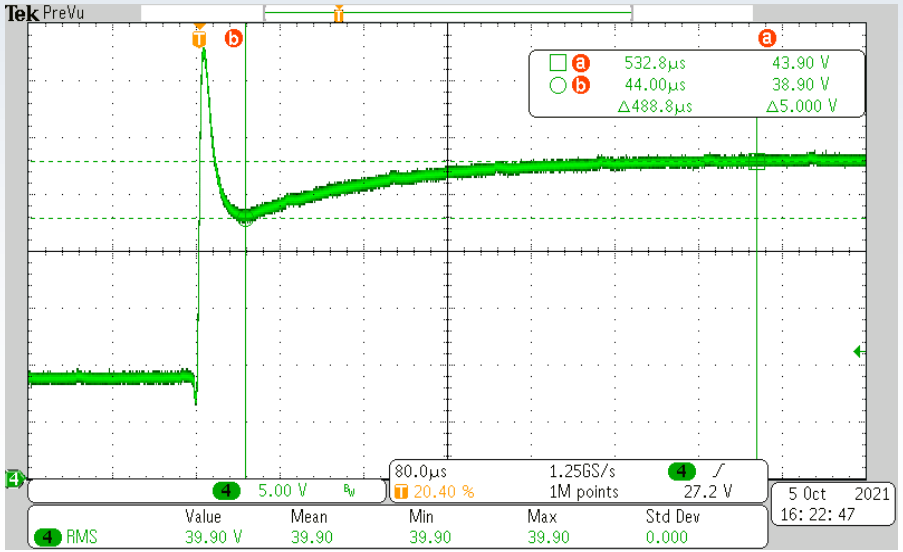
Much effort has been made to understand this including some variation of sensor settings in-flight, and some energetic beam testing under vacuum at MSSL with an engineering model

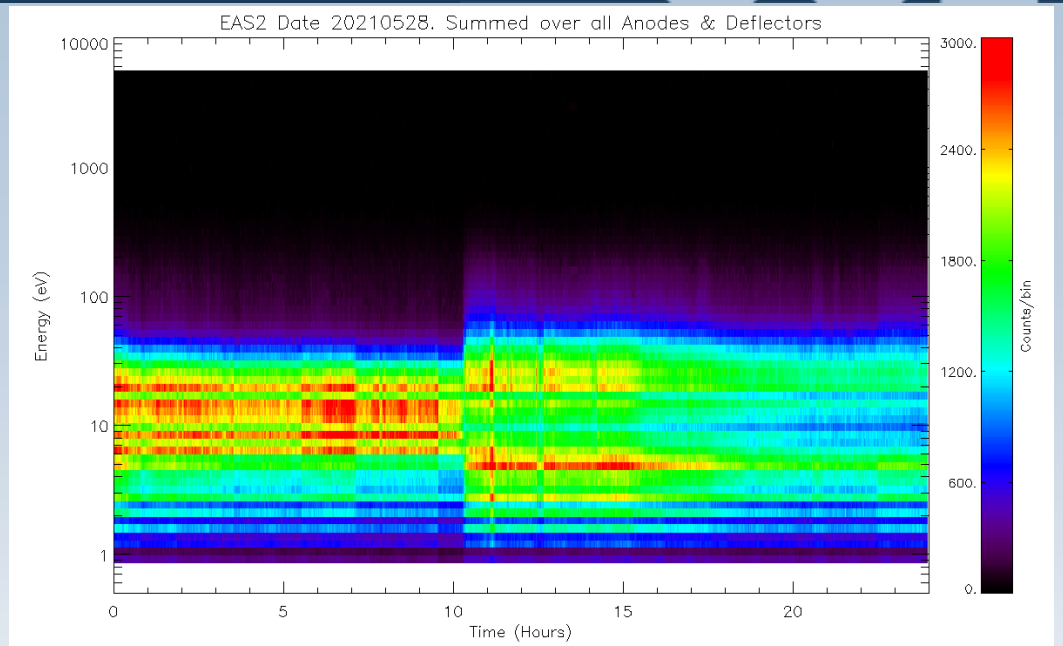
Recent evidence is suggesting that this effect is due to the too short ‘settle time’ used by EAS when it sets the inner hemisphere voltage

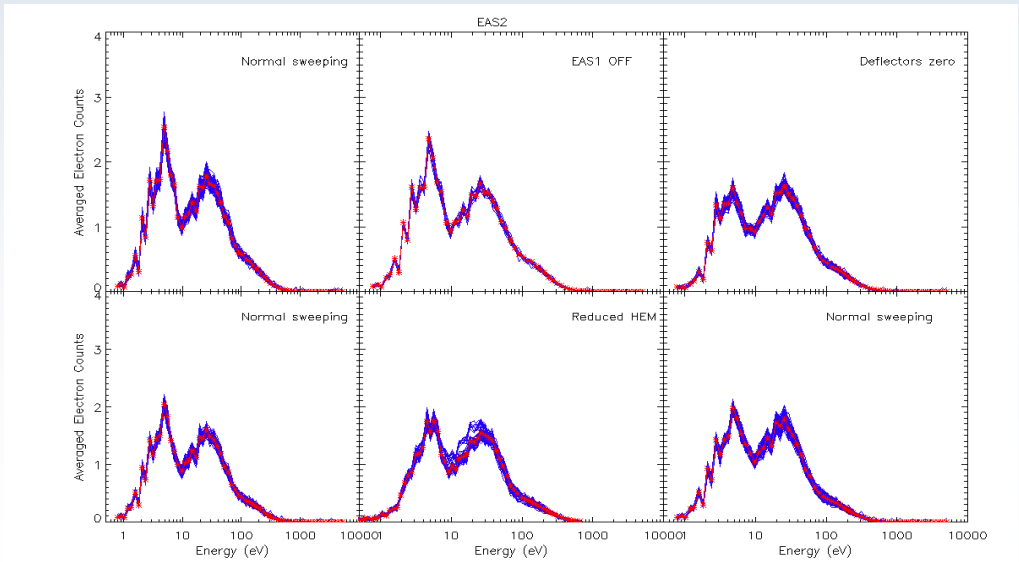
Here we can see that the hemisphere voltage step takes ~ 480 usec (a to b). In flight it is given only 50 usec.

This means (in this case) the voltage is below what is required for part of the measurement

This is still under investigation







Venus Flyby 2

- 9th August 2021

Pre-VGAM	Closest approach	Post-VGAM
EAS **ON** until 2021/08/08 18:45*	**EAS OFF** 2021/08/09 04:42	EAS back **ON** from 2021/08/09 14:36*

Time

*Includes calibration tests directly before and after switch-off

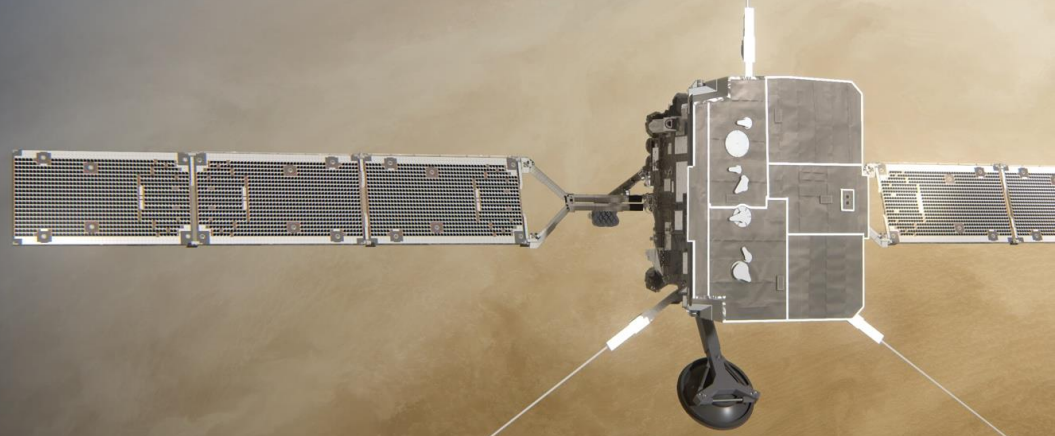
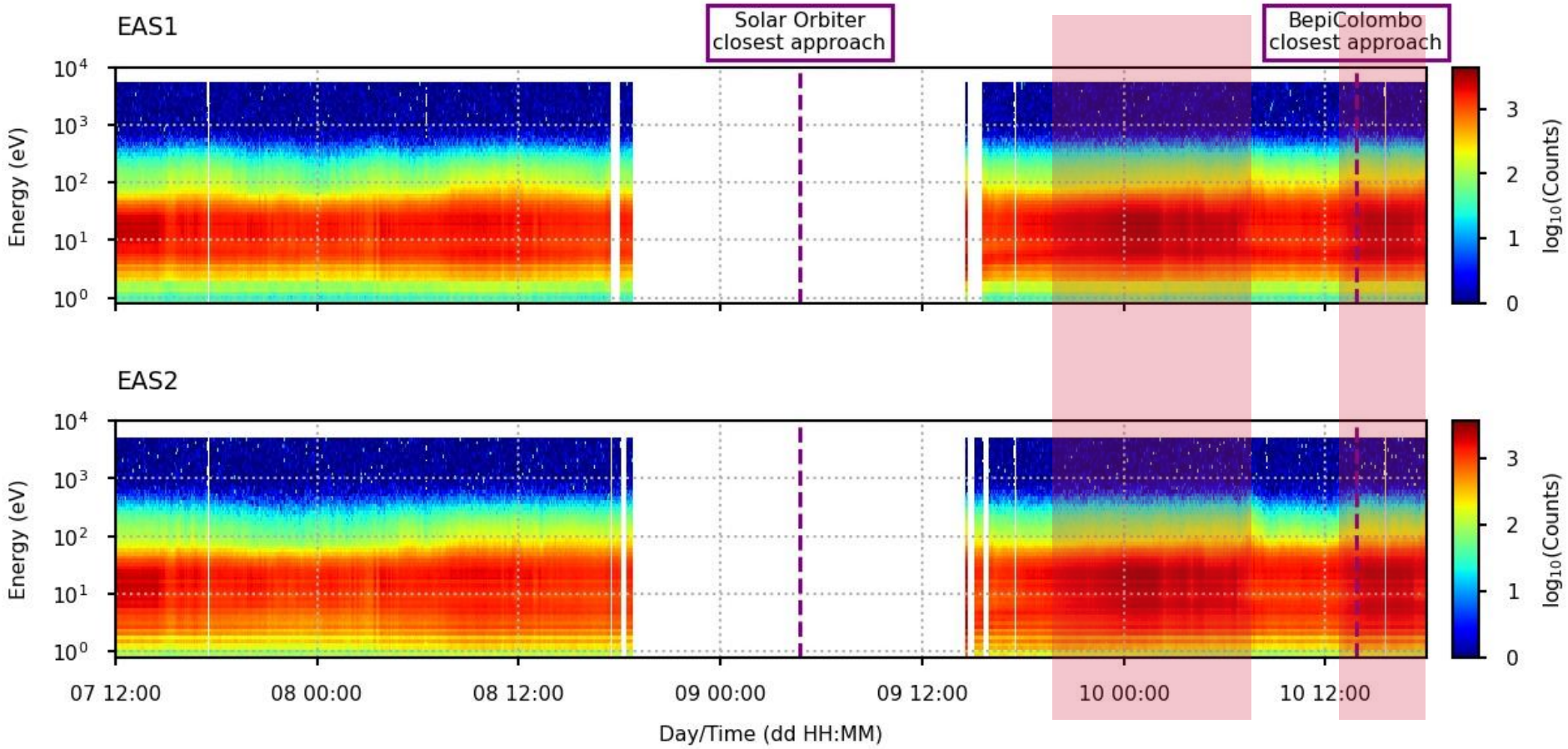


Image: ESA

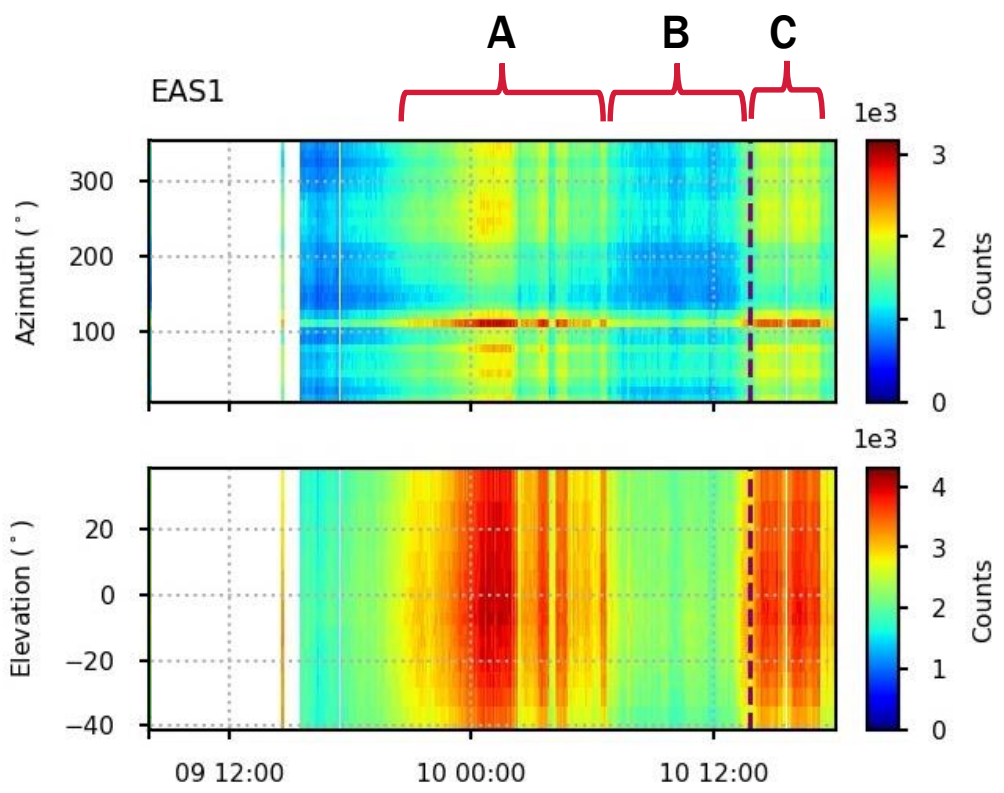
Venus Flyby 2

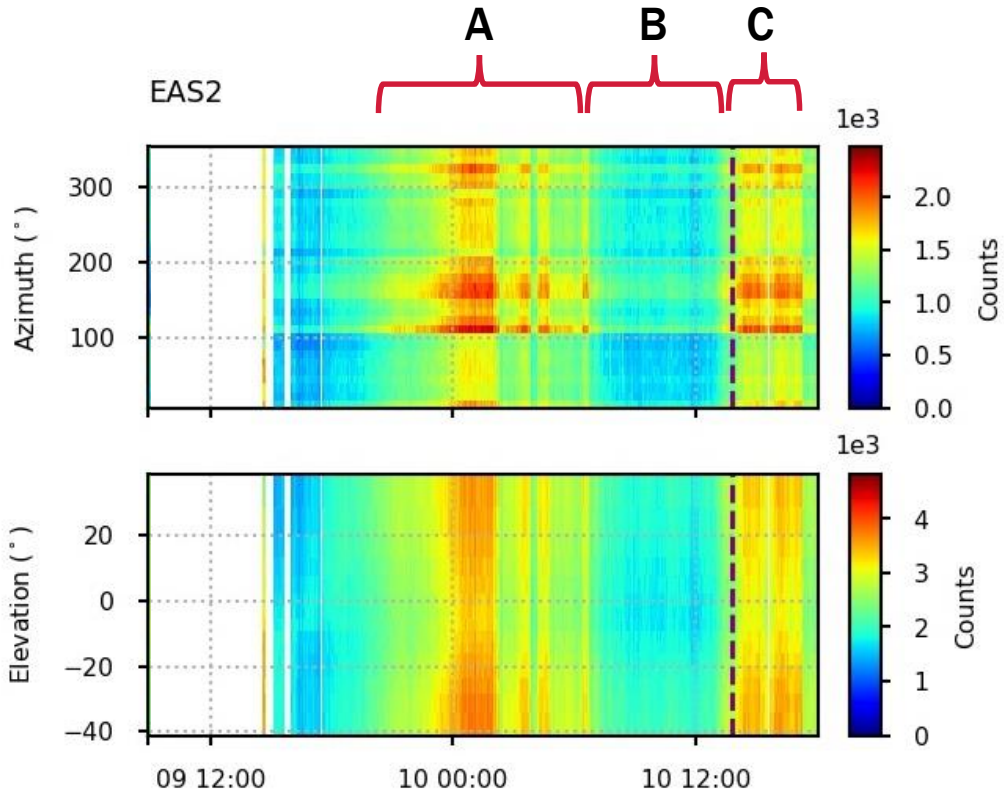
- Disturbances observed in 10-100 eV range across both sensor heads (shaded)



Venus Flyby 2

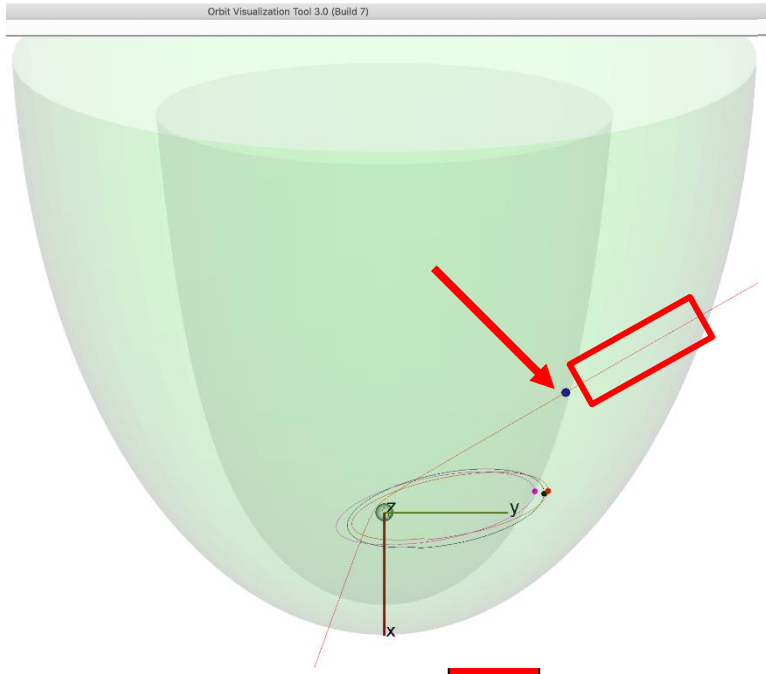
- A = 1st enhancement (some directional structure)
- B = Quiet period (~6 hrs)
- C = 2nd enhancement





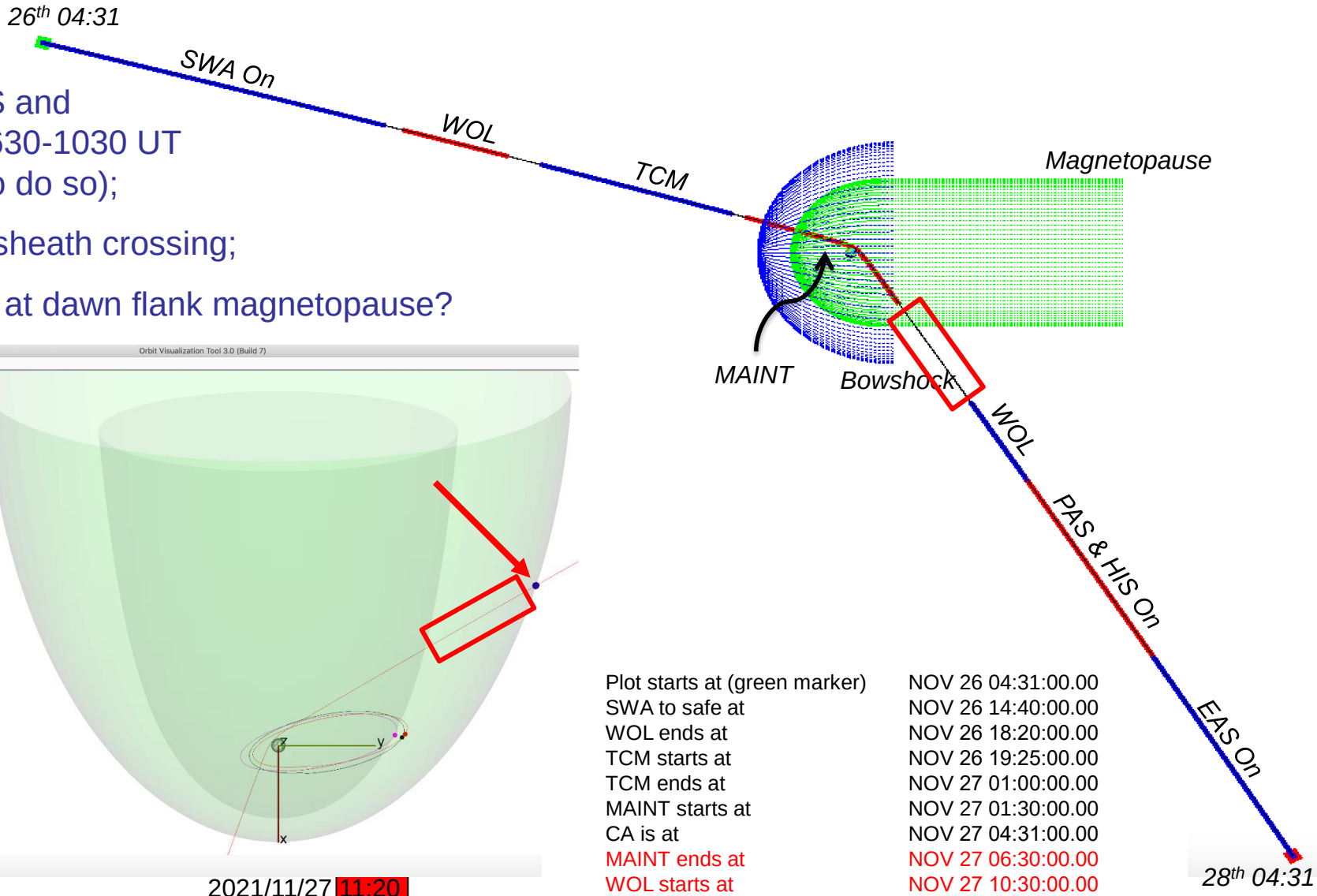
EGAM – 27 November

- We intend to try to operate SWA HIS and PAS in the 4h gap in s/c activities 0630-1030 UT (there are also calibration reasons to do so);
- This corresponds to outbound flank sheath crossing;
- Possible relevant Cluster operations at dawn flank magnetopause?



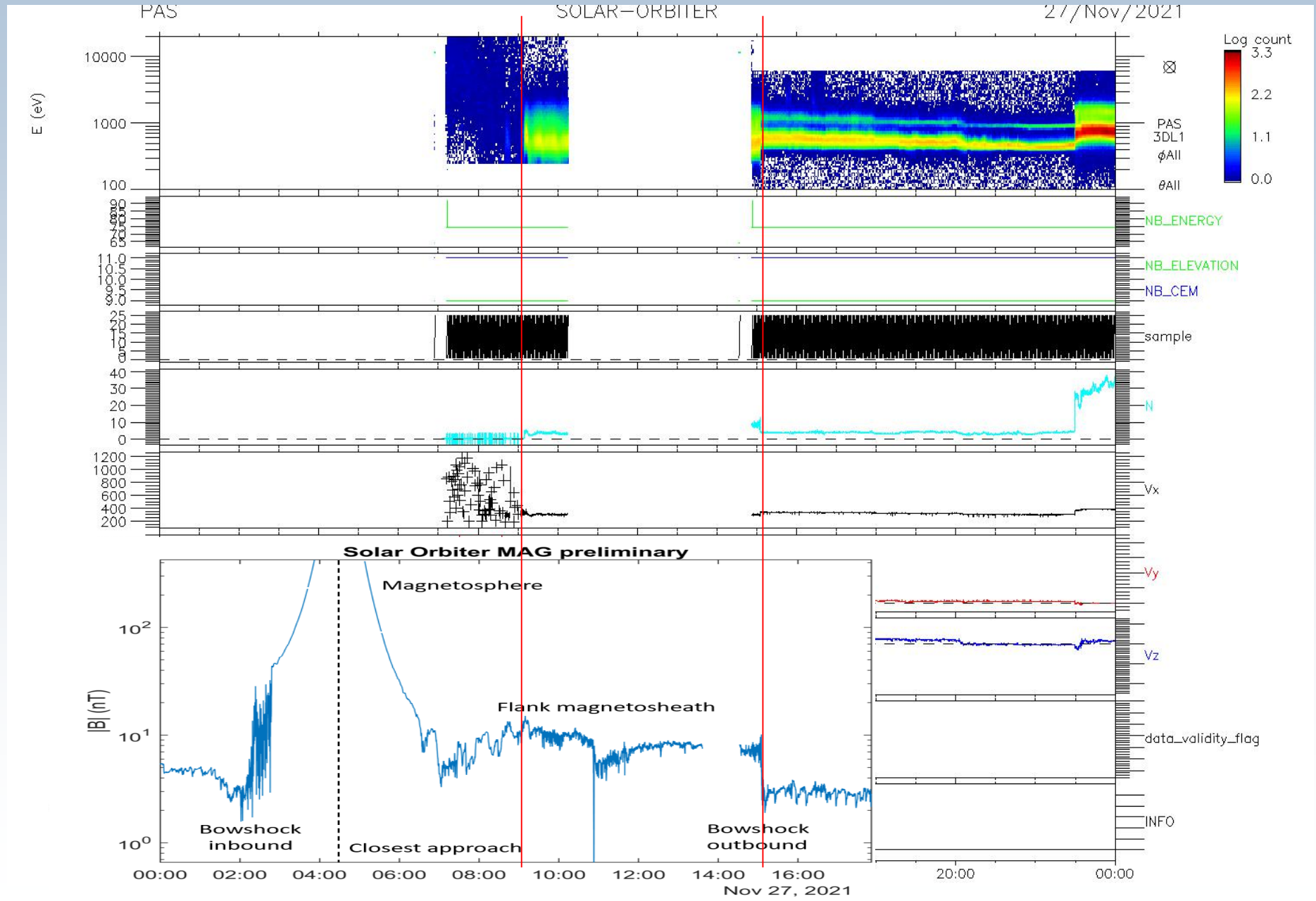
2021/11/27 05:50
SO at magnetopause flank
Cluster 34 at magnetopause,
C1C2 sheath

2021/11/27 11:20
SO at shock flank
Cluster 34 at magnetopause
C1C2 sheath



Plot starts at (green marker)	NOV 26 04:31:00.00
SWA to safe at	NOV 26 14:40:00.00
WOL ends at	NOV 26 18:20:00.00
TCM starts at	NOV 26 19:25:00.00
TCM ends at	NOV 27 01:00:00.00
MAINT starts at	NOV 27 01:30:00.00
CA is at	NOV 27 04:31:00.00
MAINT ends at	NOV 27 06:30:00.00
WOL starts at	NOV 27 10:30:00.00
WOL ends at	NOV 27 13:30:00.00
EAS back on at	NOV 27 20:30:00.00
Plot ends at (red marker)	NOV 28 04:31:00.00

SWA/PAS observations during EGAM



Cluster Data

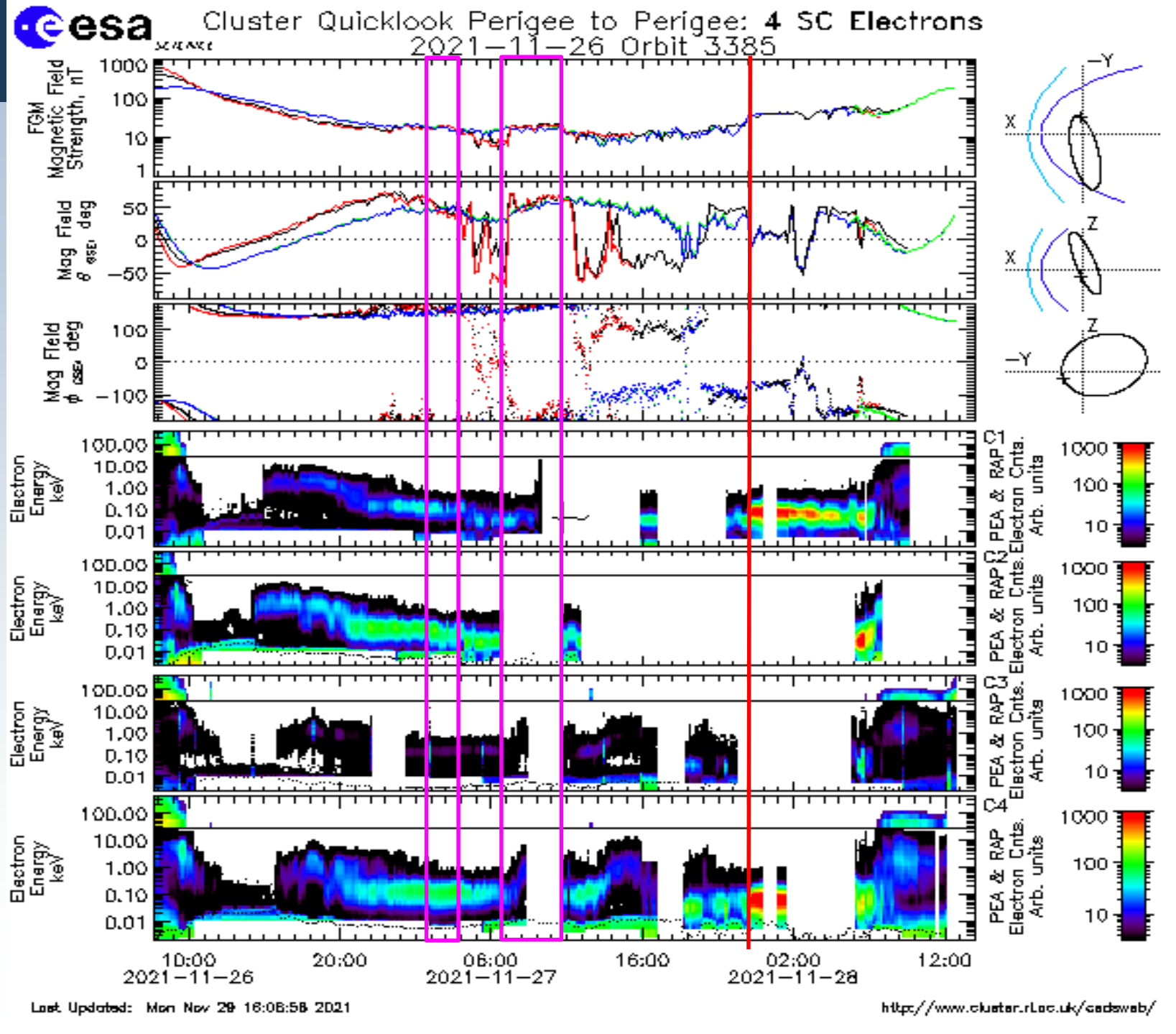
One orbit of Cluster-PEACE data from 26-28 November.

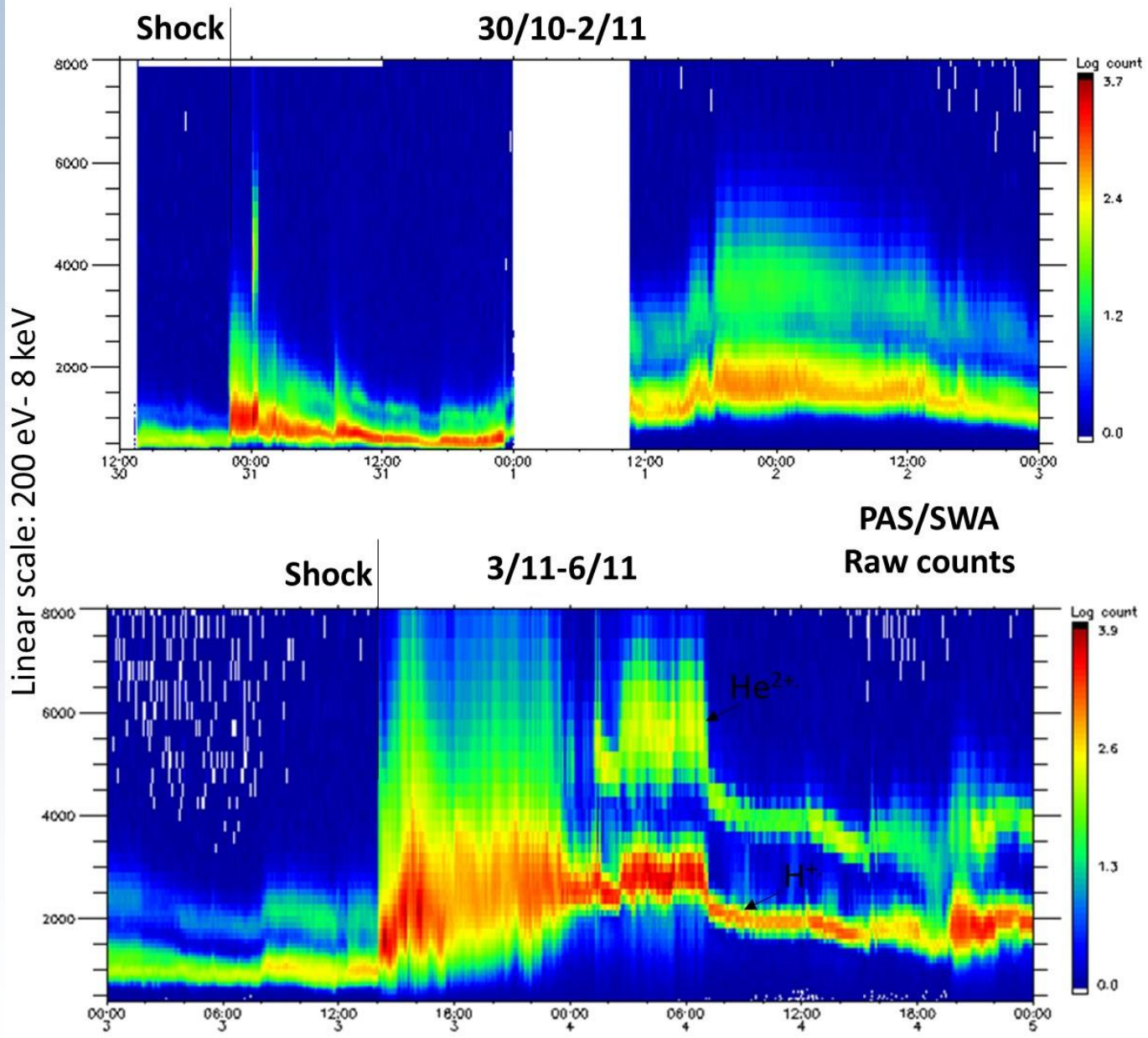
Top three panels are magnetic field data, lower four panels are electron data from Cluster 1,2,3,4.

Gaps because not all data downlinked yet.

Pink rectangles are high-data-rate Burst Mode – second one coincides with PAS seeing MP

Red line is IP shock time – see unexpected and very dense sheath

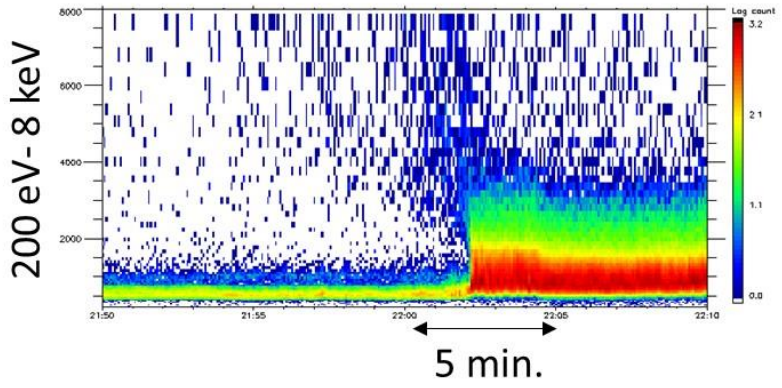




From 31/10 to 7/11, a complex and highly dynamics solar wind.

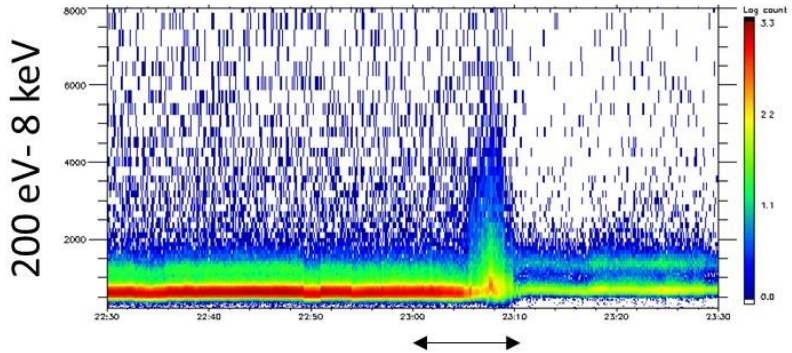
At least 2 shocks, several discontinuities and transitions from slow (300 km/s) to fast (750 km/s) winds.

Shocks with acceleration



5 min.

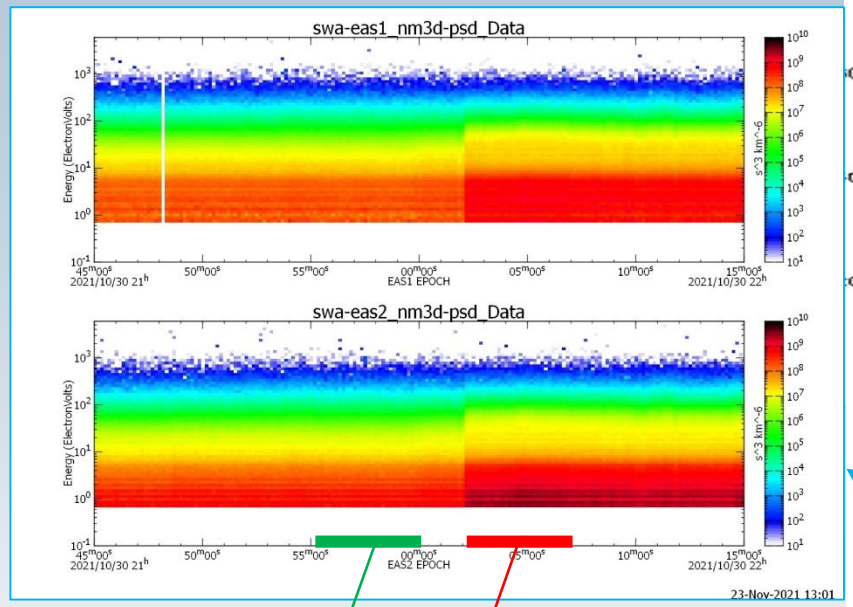
Example of short scale heating

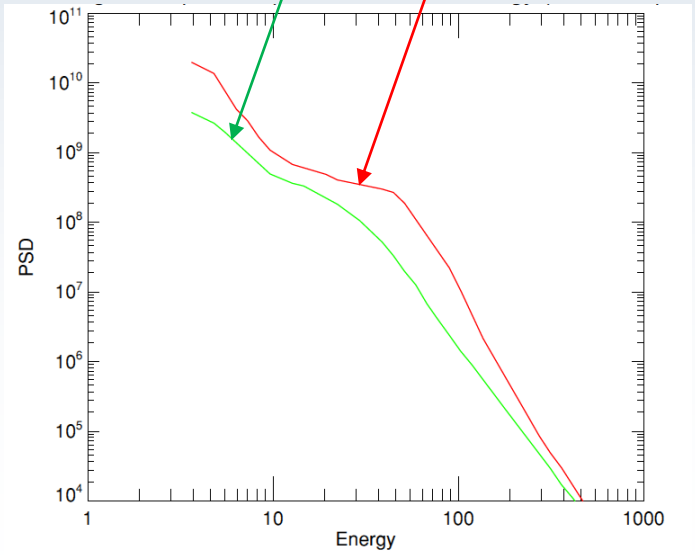


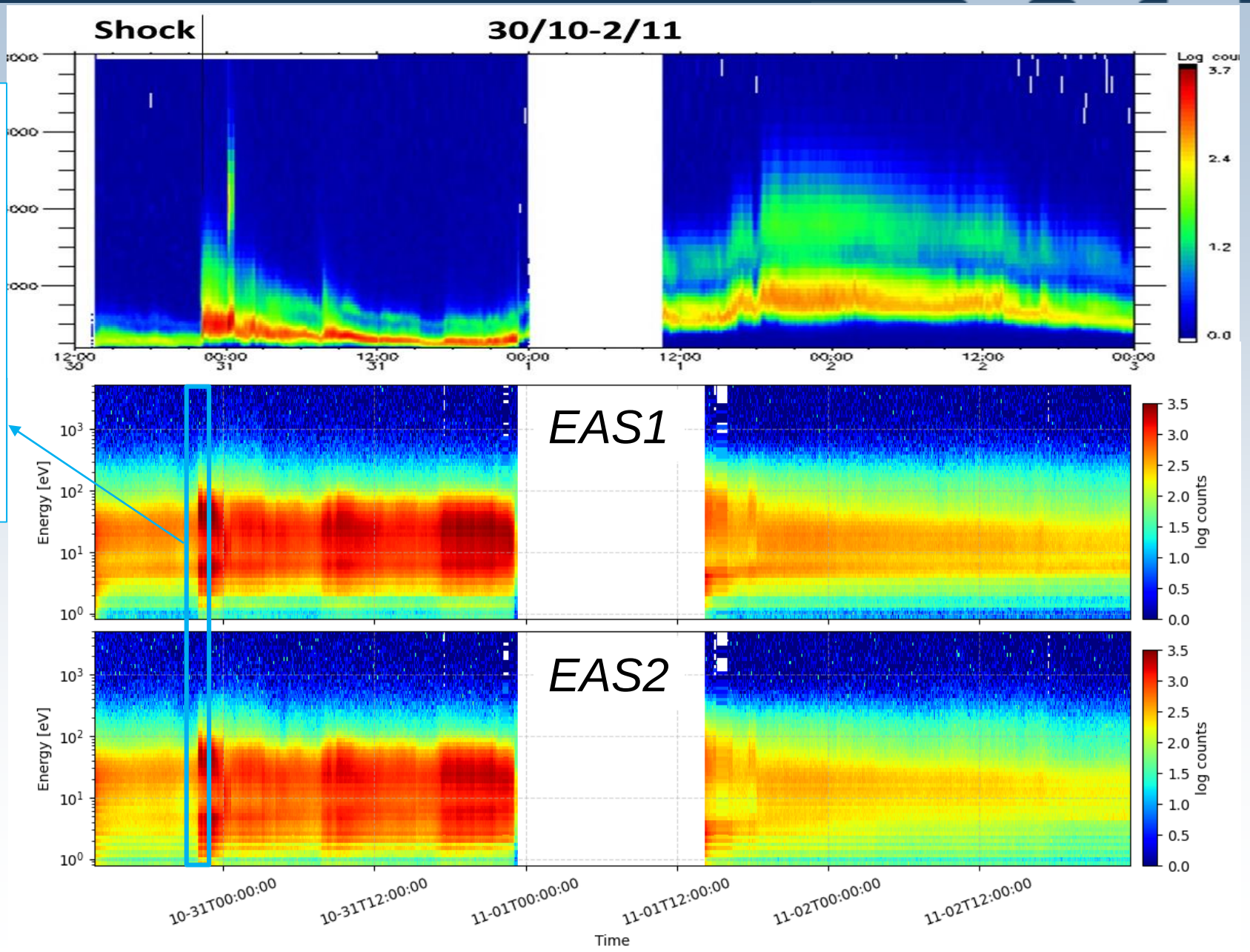
10 min.

Plots courtesy of Philippe Louarn, IRAP

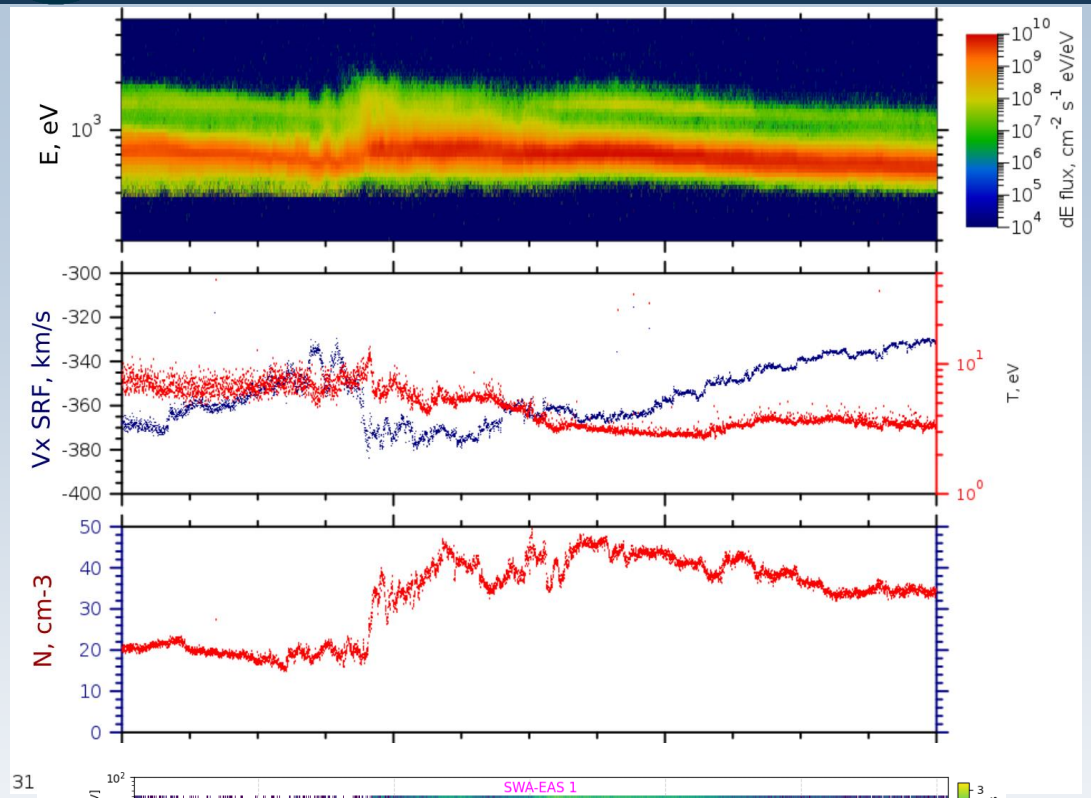
PAS & EAS Shock data

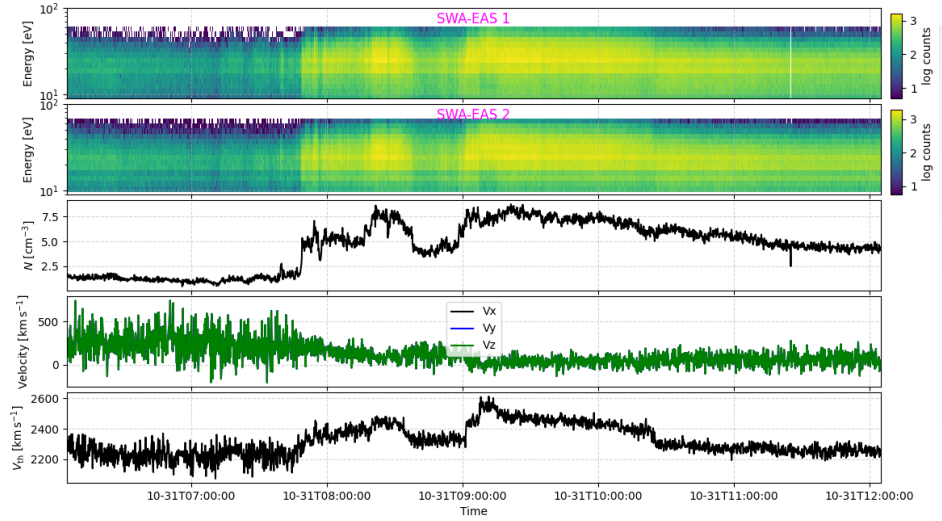


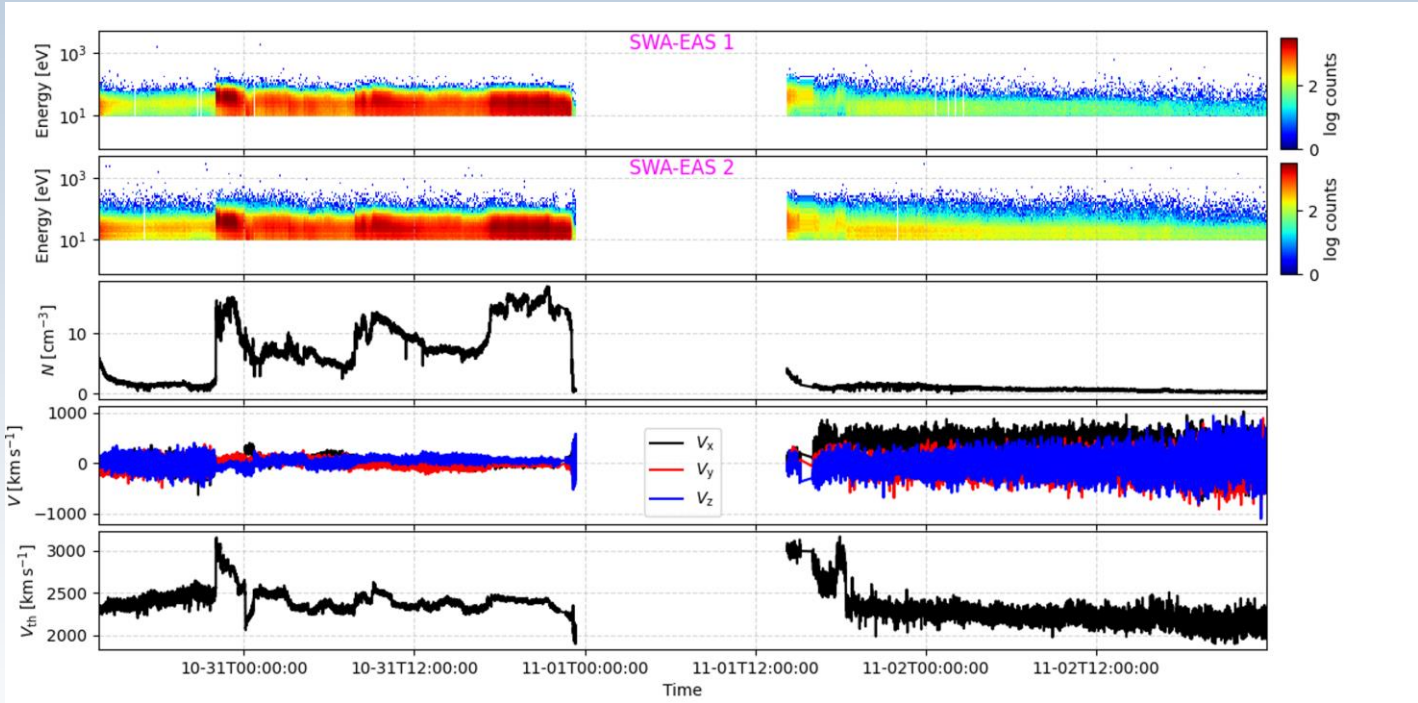




PAS & EAS observations with ground calibrated moments

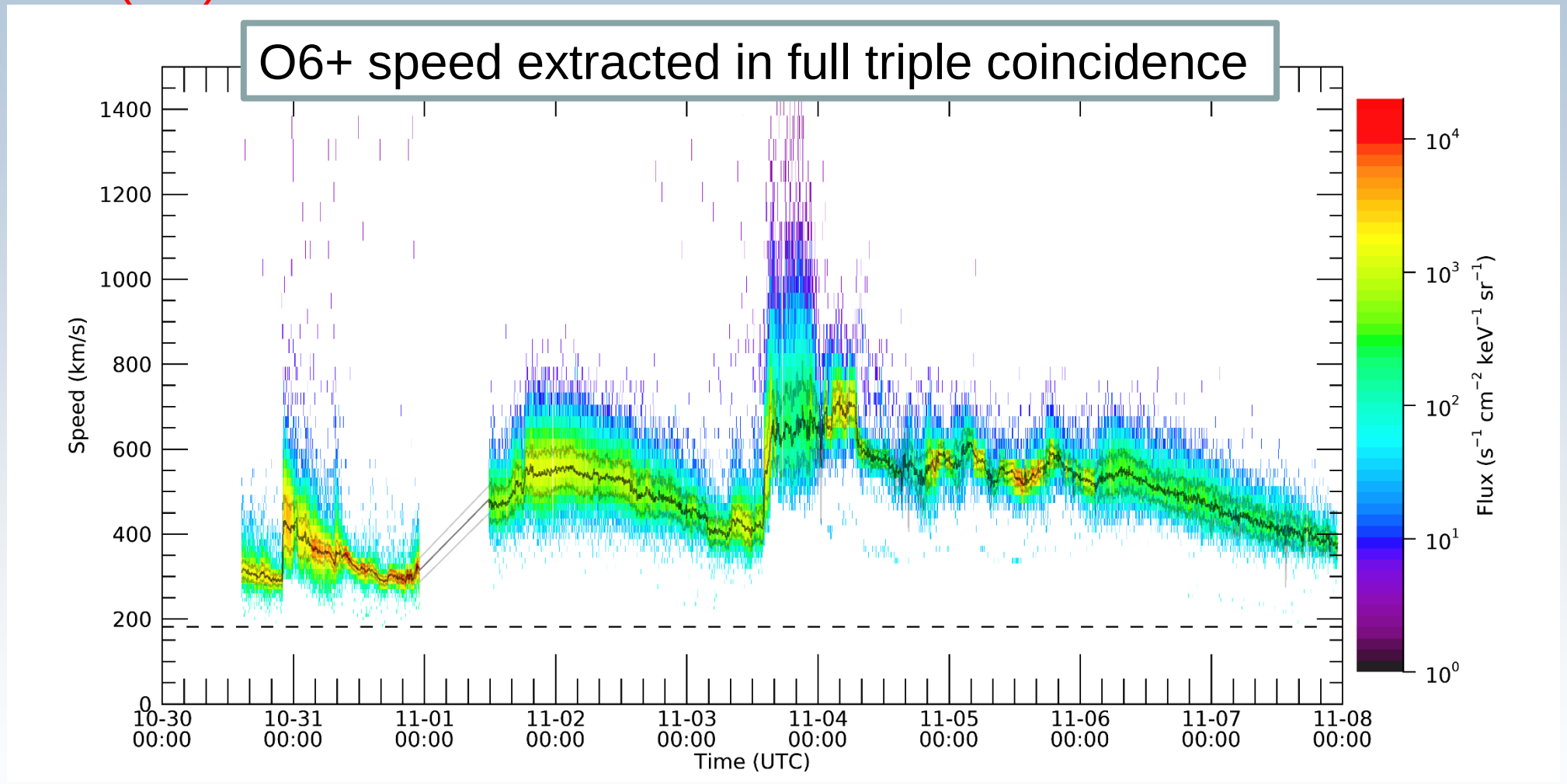






Plots courtesy A. Federov and G. Nicolaou

HIS science (1/3)

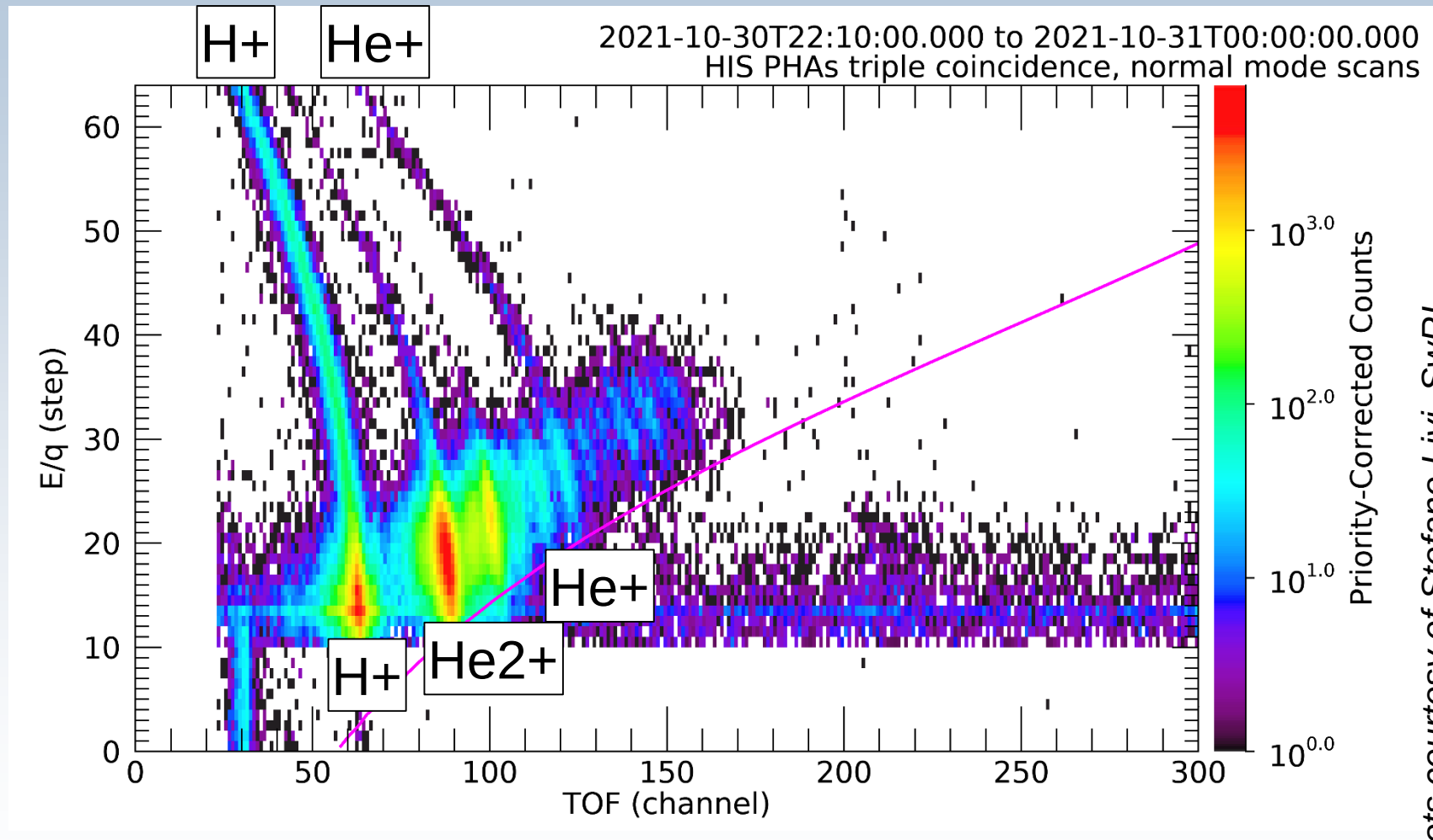


Plots courtesy of Stefano Livi, SwRI

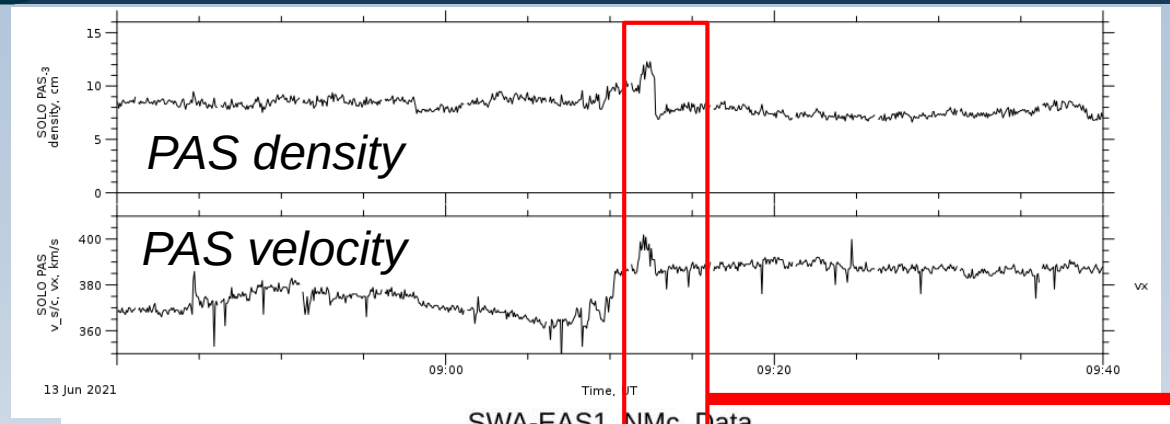
The 2021 “Halloween Storm” CMEs were an excellent opportunity for HIS!

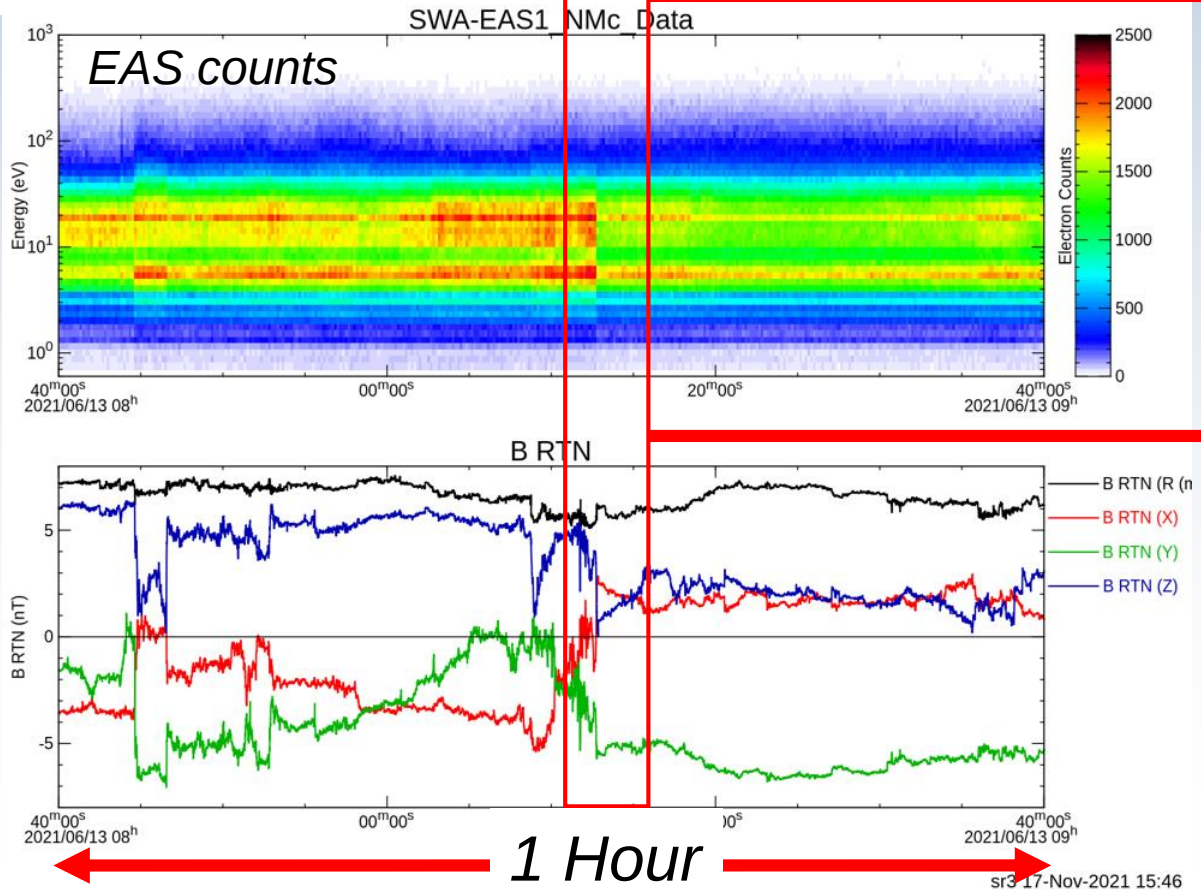
HIS Science (2/3)

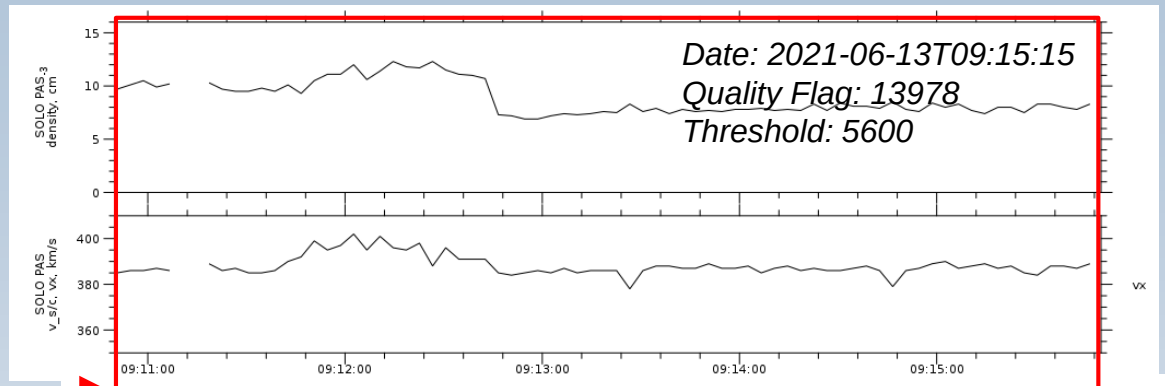
- Individual ions followed curved tracks in E/q-TOF
- Large increase in suprathermal H+ and He+, **without** corresponding increase in suprathermal He2+
- Maybe energy-dependent shock acceleration

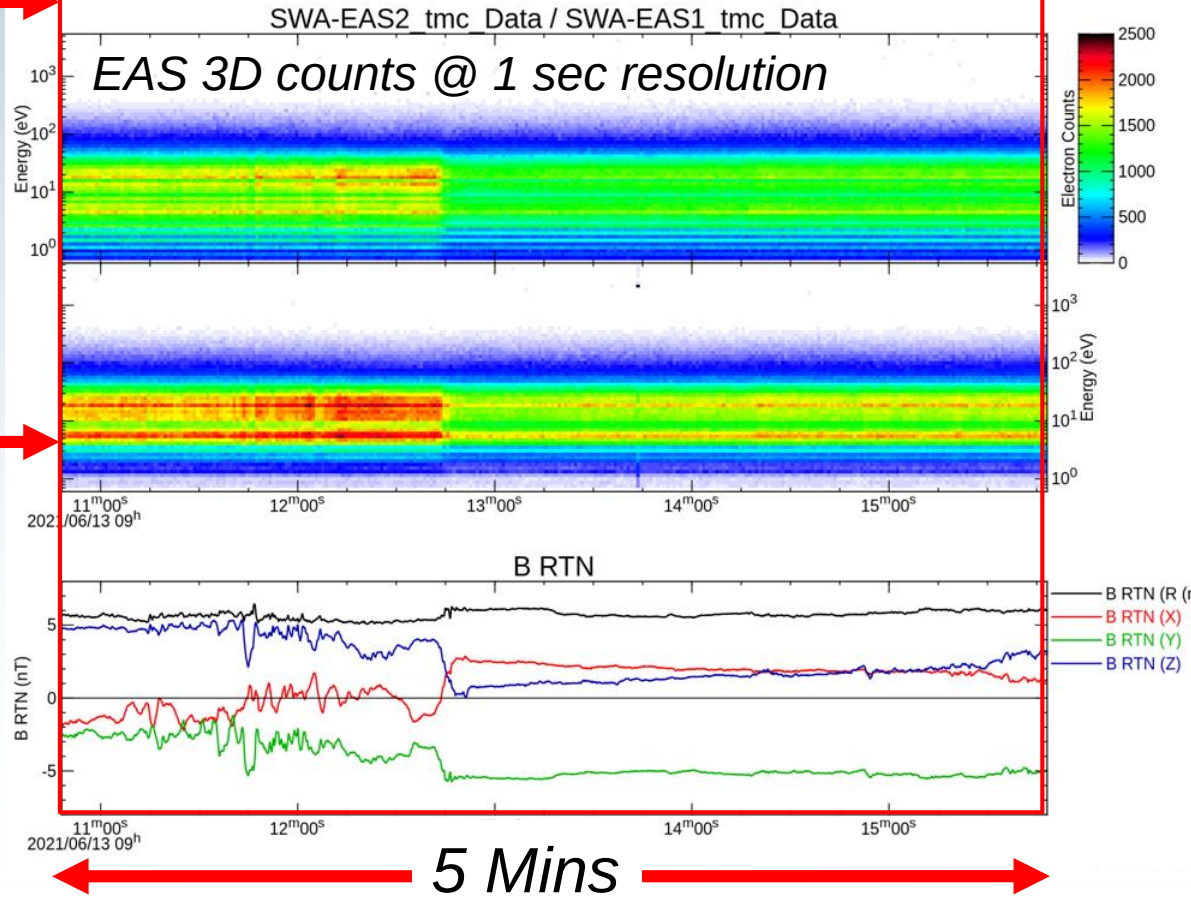


EAS ‘Shock’ Triggers (Plots from Abid Razavi)









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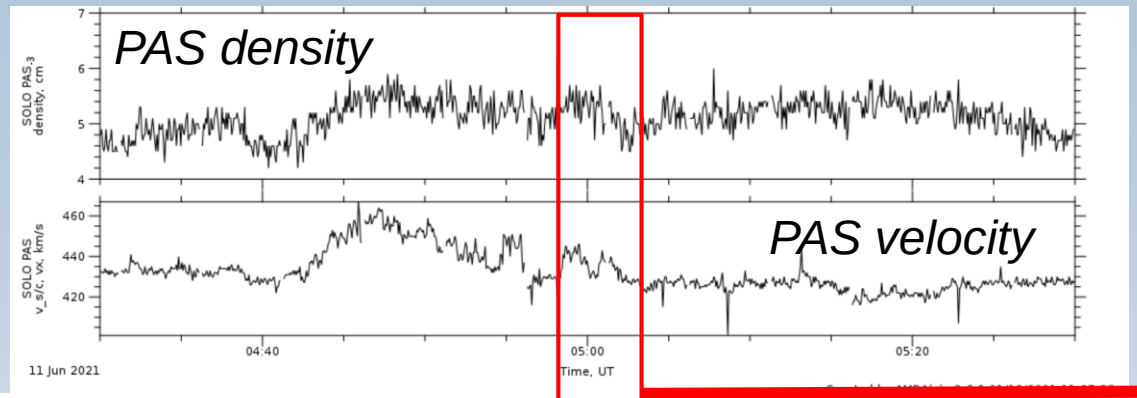
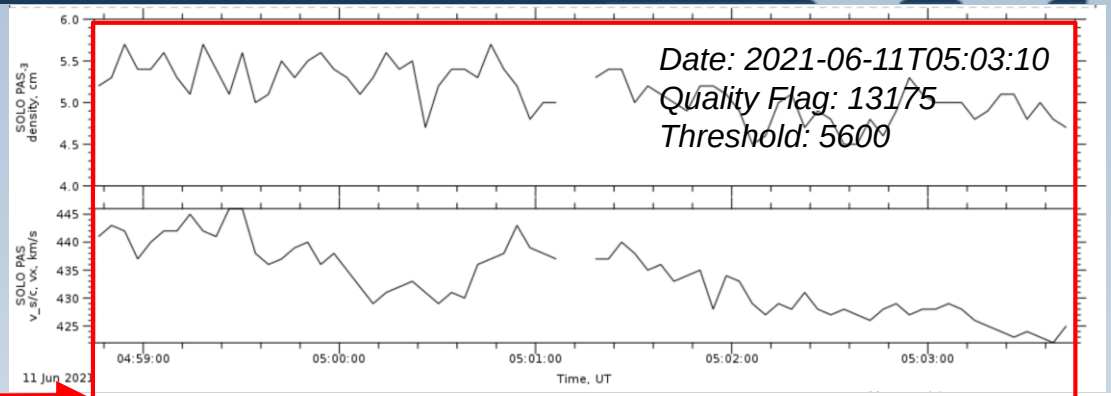
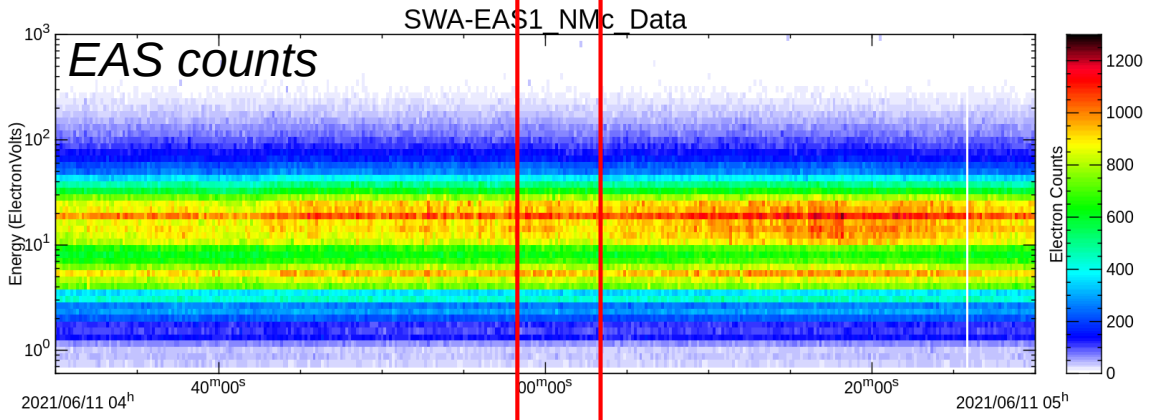
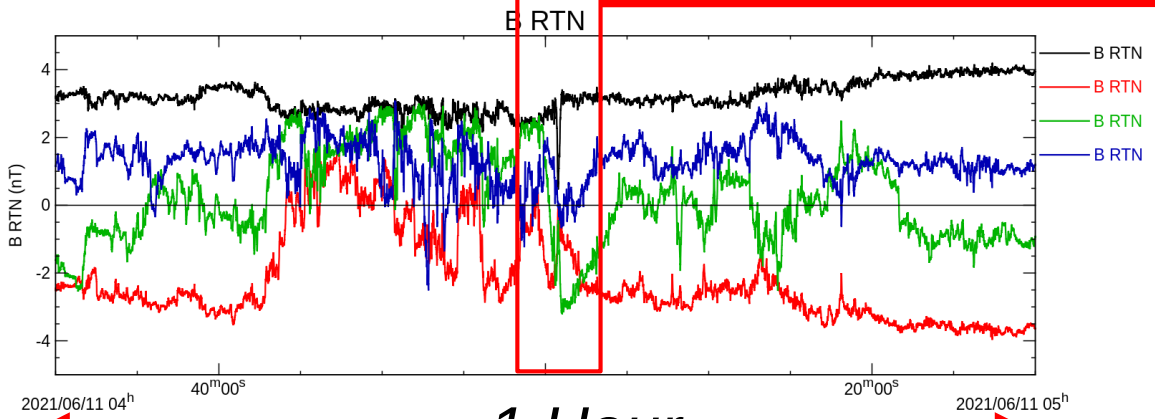
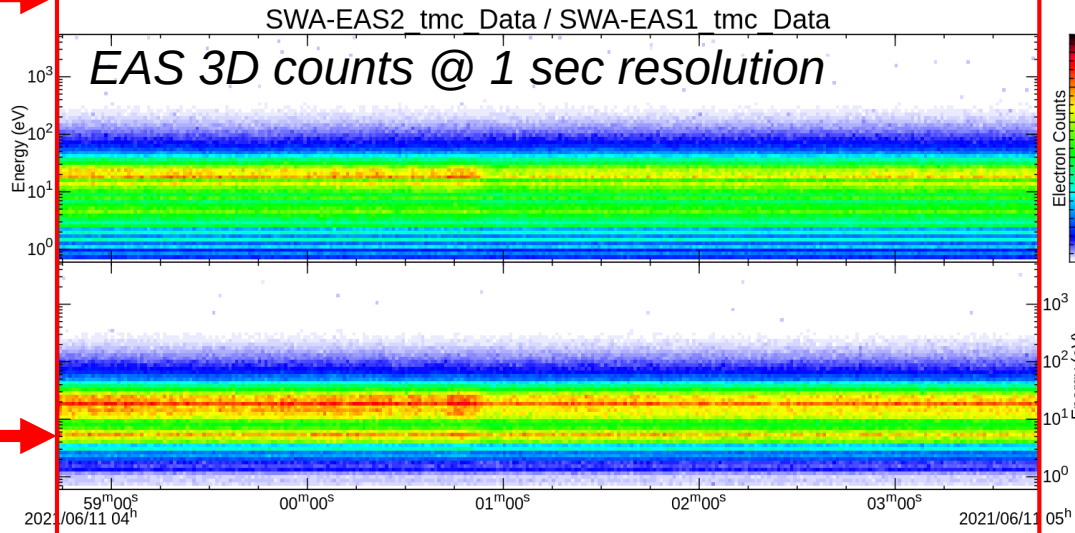
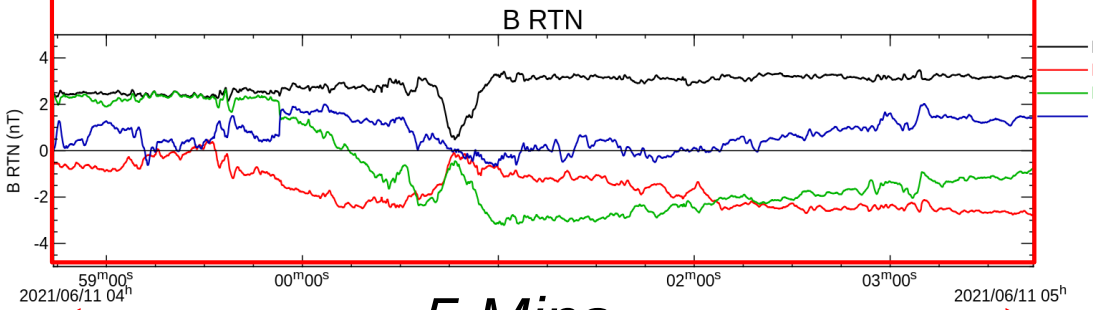








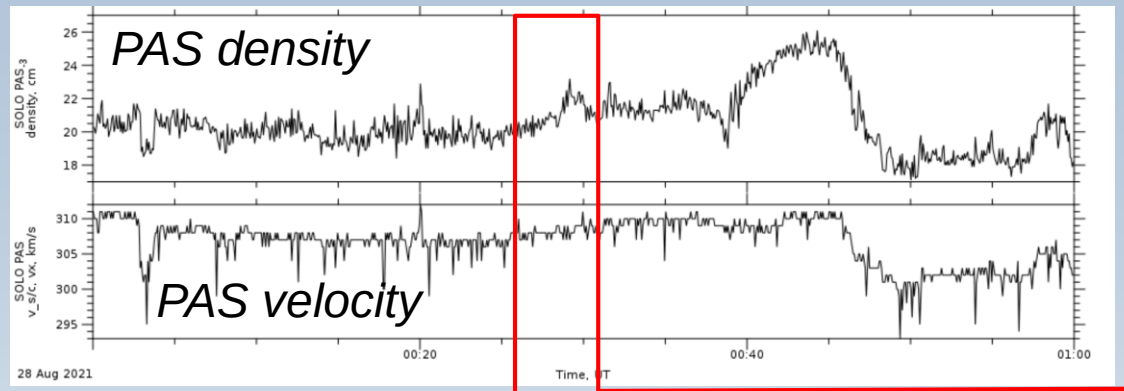


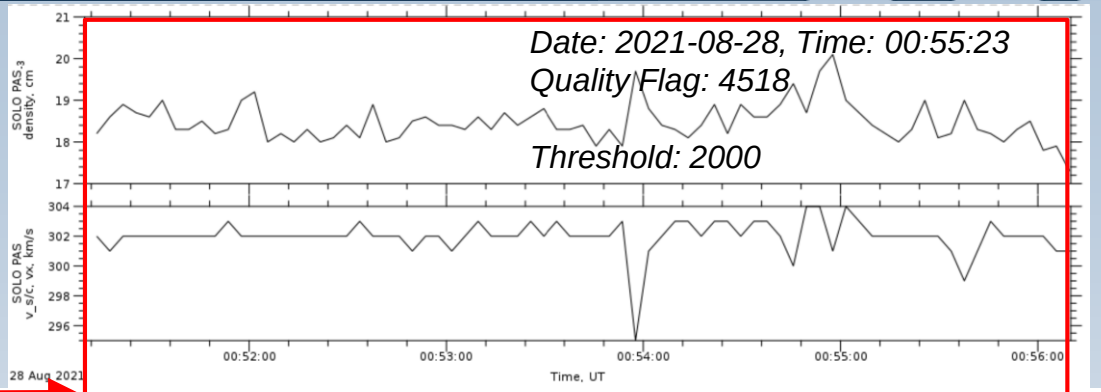


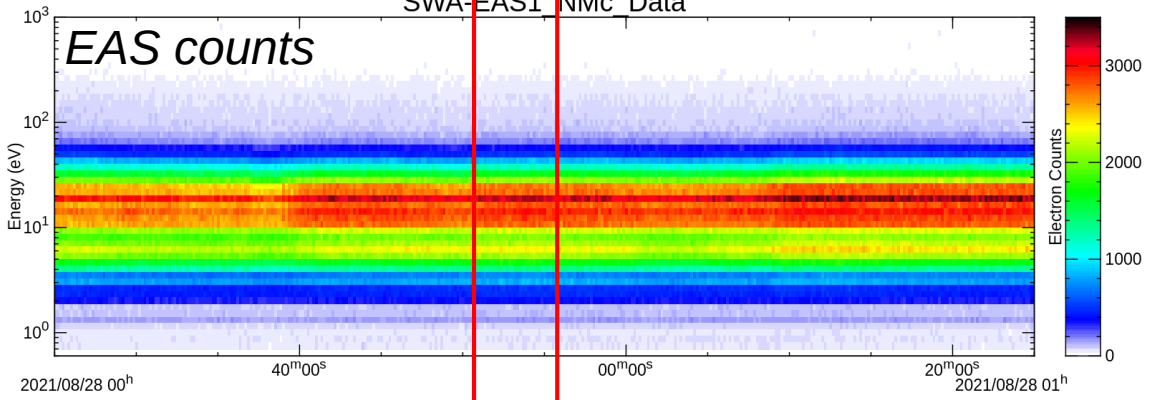
1 Hour

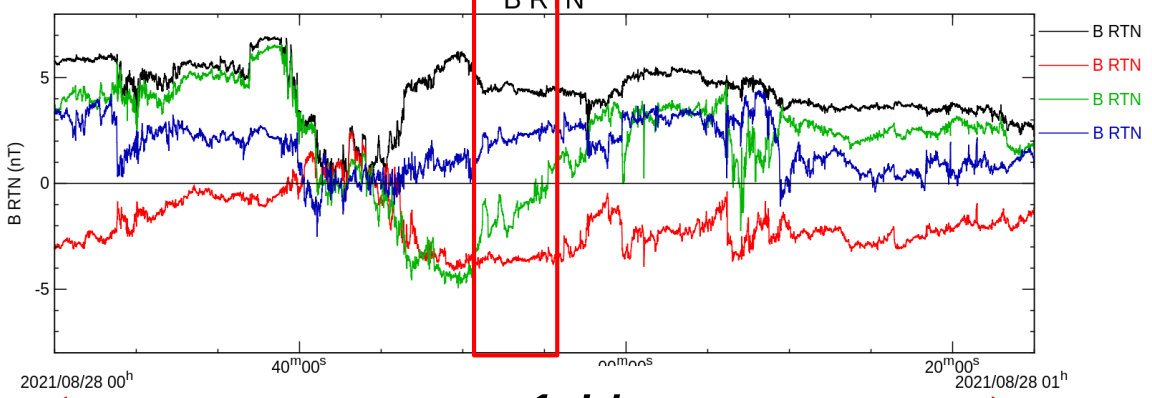
5 Mins

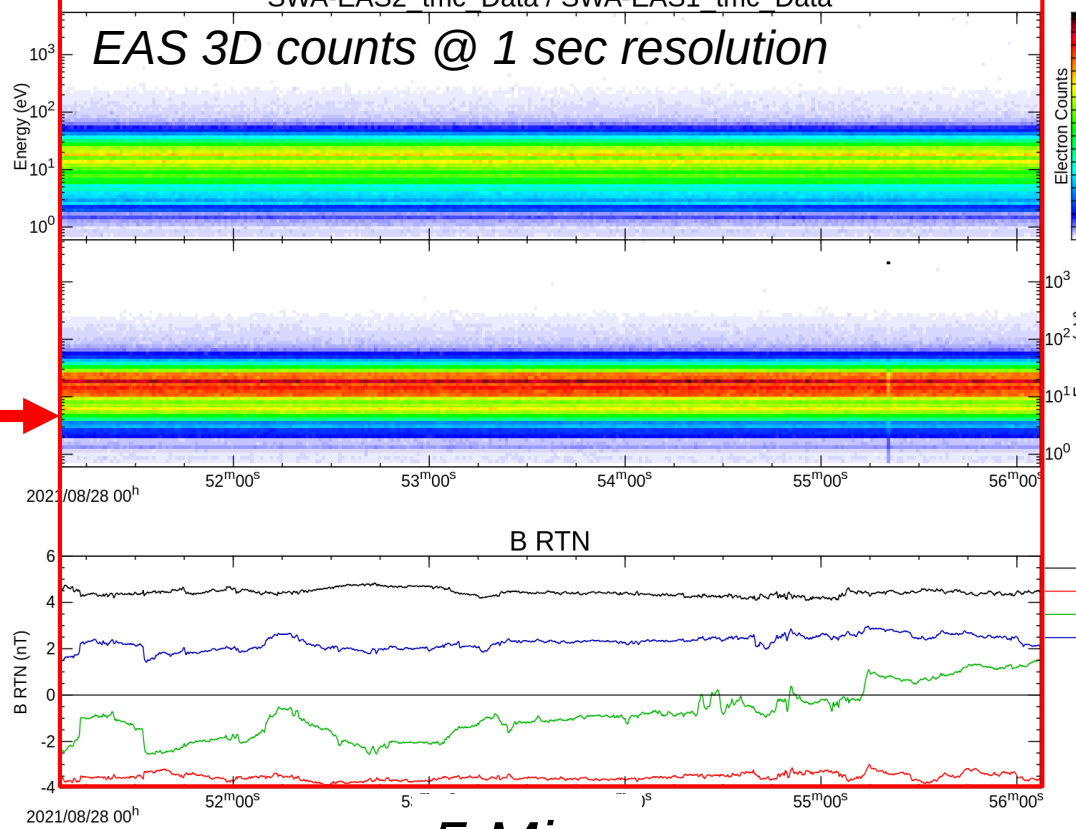
EAS 'Shock' Triggers (Plots from Abid Razavi)







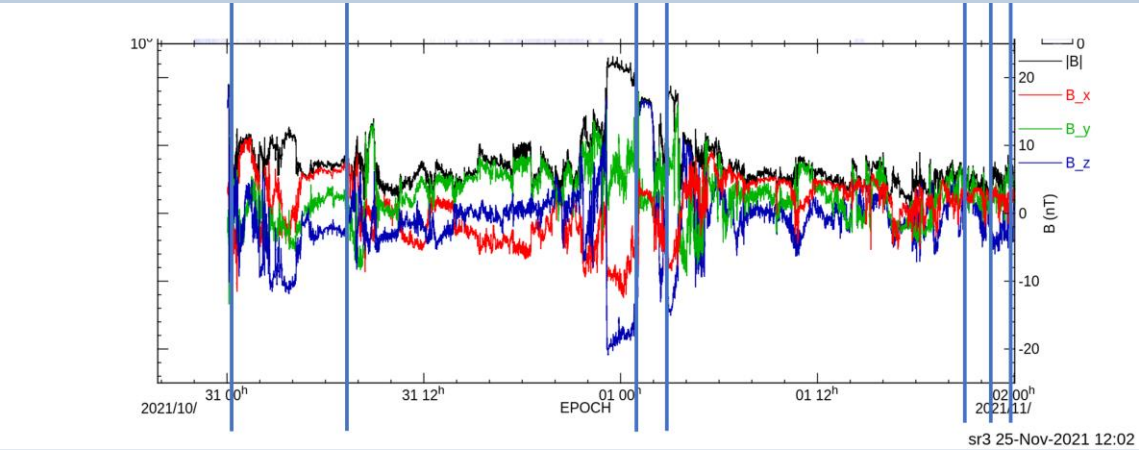




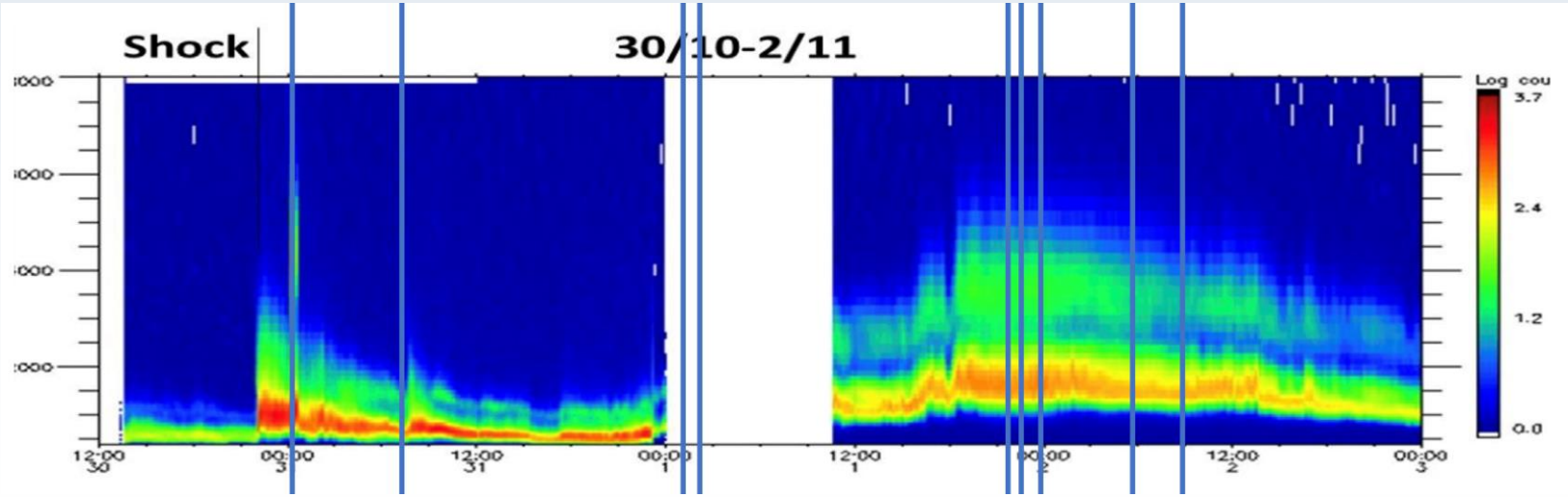
1 Hour

5 Mins

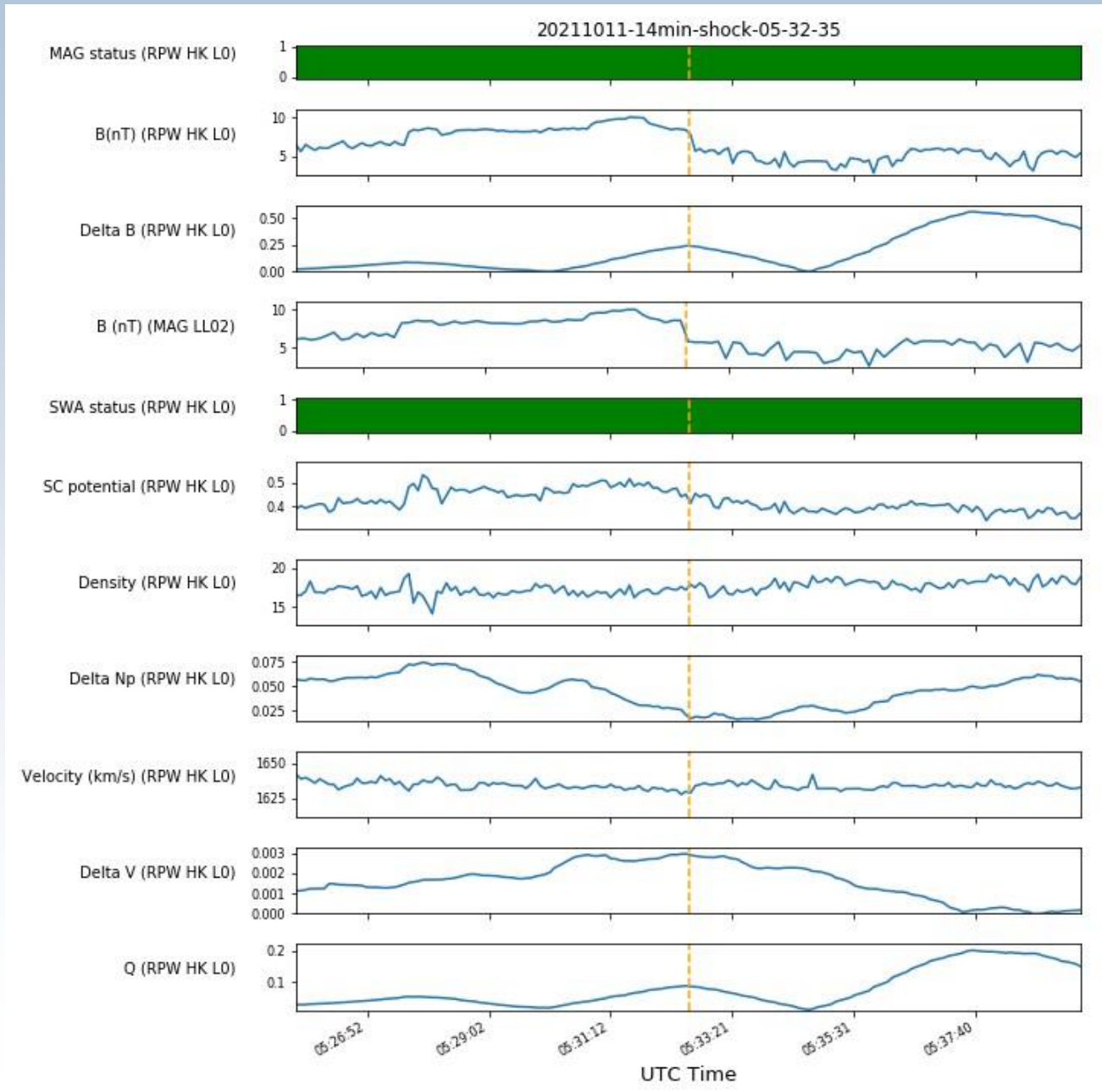
Halloween Period 2021



Date & Time	Quality Flag	Threshold
2021-10-31T00:15:41	6129	6000
2021-10-31T07:33:40	2758	2000
2021-11-01T01:08:35	8093	2000
2021-11-01T02:39:23	9158	2000
2021-11-01T21:20:10	2681	2000
2021-11-01T22:36:34	2639	2000
2021-11-01T23:52:10	3458	2000
2021-11-02T05:59:30	1886	2000
2021-11-02T08:59:45	2831	2000



- It would be good to:
  - get the PAS part of the trigger input working;
  - Understand how the trigger algorithm is working and over what timescales;
  - Try to tune it to optimally capture events of interest;
  - Probably somethingthat might need abit of trial and error over the next few months, but it would be good to start discussions here?



Summary

- Solar Orbiter EGAM and nominal mission start last weekend!
- Starting to put together some great looking datasets from SWA – hopefully more in depth analysis of some of these things will start to appear next year!
- I would really like to get the trigger mechanism working as it looks like that could be a unique high resolution dataset……

EAS L1 and L2 data products in SOAR

Status of EAS data in SOAR

- EAS data products, both L1 and L2, delivered for year 2020 was produced with our V01.00.00 software
- Since then we have identified some issues and fixed in V02.00.00 software
  - We have reprocessed 2020 EAS data and will be delivering these to the archive soon
  - These files will appear in the archive as “V02”
- Data collected this year is being produced with V02.00.00 software and are delivered to the archive regularly as “V01” files
  - All EAS distributions data is presented in EAS sensor frames
  - Elevation angles are instrument look directions
  - Azimuths are plasma flow directions
  - One issue we want to fix is the variable name of EAS[12] data in PSD units
    - We wanted this to be SWA_EAS[12]_NM3D_PSD_Data
    - But it is SWA_EAS[12]_Data as it stands
    - We will correct this for all L2 PSD data delivered so far soon
- We are now collecting “trigger mode” 3D data which is our high cadence 3D data.
- Soon will be delivering this data to the archive once the archive whitelists our trigger 3D data

Level-1 EAS Nominal 3D distributions

- Each EAS sensor measures 3D distributions every second but only every 10 or 100 or 400 distribution is saved and sent down depending on available telemetry

Descriptor	**solo_L1_swa-eas[12]-NM3D**	
Timetag1	EPOCH	SPICE correct CDF TT2000 epoch
Timetag2	SCET	Spacecraft Elapsed time in ticks
Data	SWA_EAS[12]_Data	EAS[12] 3D counts data array [16x64x32]
Elevation bin centres	SWA_EAS_ELEVATION	Elevation bin centres – these are instrument look directions
Azimuthal bin centres	SWA_EAS_AZIMUTH	Azimuthal bin centres – these are in plasma flow directions
Energy bin centres	SWA_EAS[12]_ENERGY	Energy bin centres
Data coordinate system	SOLO_SWA_EAS[12]-SCI	Data is given is sensor science frame

Level-1 EAS Single energy Strahl data

- A single energy slice of measured 3D distribution is saved separately and send down every 100 seconds as low latency data

Descriptor	**solo_L1_swa-eas[12]-SSc**	
Timetag1	EPOCH	SPICE correct CDF TT2000 epoch
Timetag2	SCET	Spacecraft Elapsed time in ticks
Data	SWA_EAS[12]_SS_Data	EAS[12] counts measured for one strahl energy - data array [16x32]
Elevation bin centres	SWA_EAS_ELEVATION	Elevation bin centres – these are instrument look directions
Azimuthal bin centres	SWA_EAS_AZIMUTH	Azimuthal bin centres – these are in plasma flow directions
Energy bin centres	SWA_EAS[12]_ENERGY	The Energy Bin (eV) used to obtain the Single Strahl
Data coordinate system	SOLO_SWA_EAS[12]-SCI	Data is given is sensor science frame

Level-1 EAS onboard selected pitch angle data

- EAS collects high resolution (125ms) electron data for 2 elevations, 64 energies and 32 azimuths based on

Descriptor	**solo_L1_swa-eas-padc**	
Timetag1	EPOCH	SPICE correct CDF TT2000 epoch
Timetag2	SCET	Spacecraft Elapsed time in ticks
Data	SWA_EAS_BM_Data	EAS[12] counts measured for one strahl energy - data array [2x64x32]
Elevation bin centres	SWA_EAS_ELEVATION	Elevation bin centres of elevations used for data collection – these are instrument look directions
Azimuthal bin centres	SWA_EAS_AZIMUTH	Azimuthal bin centres – these are in plasma flow directions
Energy bin centres	SWA_EAS[12]_ENERGY	Energy bin centres in eV
Data coordinate system	SOLO_SWA_EAS[12]-SCI	Data is given is sensor science frame
EAS sensor used	SWA_EAS_EasUsed	

Level-1 EAS onboard calculated partial moments

- SWA-DPU calculates partial moments from both EAS sensors at a 4 sec cadence for three energy ranges and 4 look directions
- The three energy ranges are low, core-halo and strahl energies
- The four look directions are EAS1 only, EAS1 overlap with EAS2, EAS2 only and EAS2 overlap with EAS1 directions
- File descriptor is: **solo_L1_swa-eas-OnbPartMoms**
- All partial moments are presented in sensor frame i.e. SOLO_SWA_EAS[12]-SCI
- Total of12 sets of partial moments are provided in this cdf file
  - Variable names contain energy range, sensor coverage and the moment name
    - SWA_EAS[sensor]_[only/overlap]_[Low_Ene/Core_Halo/Strahl]_[N/V/H/P]
  - EPOCH, EPOCH_1 are CDF_TIME_TT2000 values from EAS1 and EAS2, respectively
  - SCET, SCET_1 are spacecraft elapsed time from EAS1 and EAS2, respectively
  - Each set of partial moments have
    - N, Vx, Vy, Vz, Hx, Hy, Hz, Pxx, Pxy, Pxz, Pyx, Pyy, Pyz, Pzx, Pzy,Pzz

Level-2 EAS Nominal 3D distributions:

- Calibrated EAS 3D distributions provided in three units i.e. PSD, DNF and DEF

Descriptor	**solo_L1_swa-eas[12]-nm3d-[psd/dnf/def]**	
Timetag1	EPOCH	SPICE correct CDF TT2000 epoch
Data	SWA_EAS[12]_Data SWA_EAS[12]_NM3D_DNF_Data SWA_EAS[12]_NM3D_DEF_Data	EAS[12] 3D data array [16x64x32] of PSD/DNF/DEF
Elevation bin centres	SWA_EAS_ELEVATION	Elevation bin centres – these are instrument look directions
Azimuthal bin centres	SWA_EAS_AZIMUTH	Azimuthal bin centres – these are in plasma flow directions
Energy bin centres	SWA_EAS[12]_ENERGY	Energy bin centres in eV
Data coordinate system	SOLO_SWA_EAS[12]-SCI	Data is given is sensor science frame

Level-2 EAS Single energy Strahl data

- Calibrated single energy strahl data in science units i.e. PSD, DNF, DEF

Descriptor	**solo_L1_swa-eas[12]-ss-[psd/dnf/def]**	
Timetag1	EPOCH	SPICE correct CDF TT2000 epoch
Data	SWA_EAS[12]_SS_PSD_Data SWA_EAS[12]_SS_DNF_Data SWA_EAS[12]_SS_DEF_Data	EAS[12] strahl data data array [16x32] in PSD/DNF/DEF
Elevation bin centres	SWA_EAS_ELEVATION	Elevation bin centres – these are instrument look directions
Azimuthal bin centres	SWA_EAS_AZIMUTH	Azimuthal bin centres – these are in plasma flow directions
Energy bin centres	SWA_EAS[12]_ENERGY	The Energy Bin (eV) used to obtain the Single Strahl
Data coordinate system	SOLO_SWA_EAS[12]-SCI	Data is given is sensor science frame

Level-2 EAS onboard selected pitch angle data

- Calibrated EAS onboard selected pitch angle data in PSD/DNF/DEF units

Descriptor	**solo_L1_swa-eas-pad-[psd/dnf/def]**	
Timetag1	EPOCH	SPICE correct CDF TT2000 epoch
Data	SWA_EAS_PAD_PSD_Data SWA_EAS_PAD_DNF_Data SWA_EAS_PAD_DEF_Data	EAS[12] burst data array [2x64x32] in PSD/DNF/DEF
Elevation bin centres	SWA_EAS_ELEVATION	Elevation bin centres of elevations used for data collection – these are instrument look directions
Azimuthal bin centres	SWA_EAS_AZIMUTH	Azimuthal bin centres – these are in plasma flow directions
Energy bin centres	SWA_EAS[12]_ENERGY	Energy bin centres in eV
Data coordinate system	SOLO_SWA_EAS[12]-SCI	Data is given is sensor science frame
EAS sensor used	SWA_EAS_EasUsed	