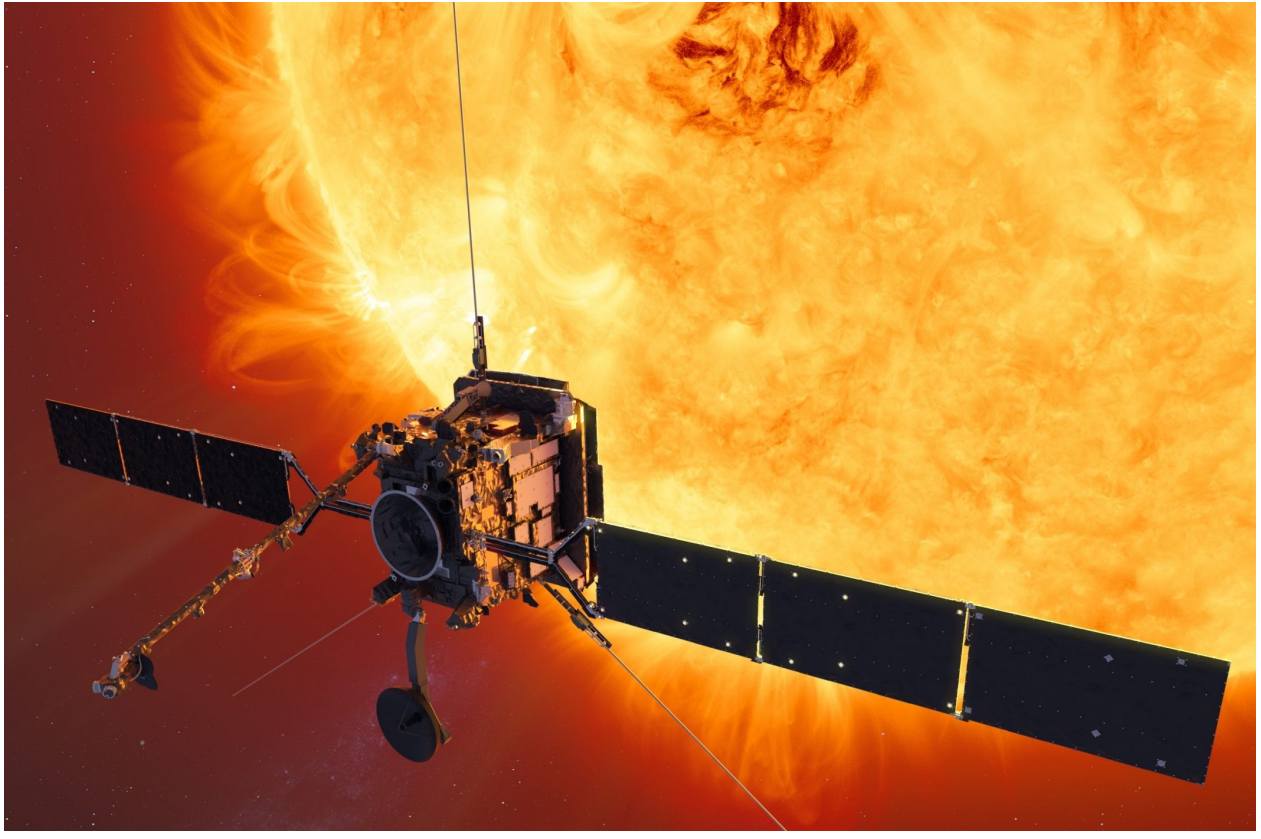
First Results from the Energetic Particle Detector (EPD) on Solar Orbiter



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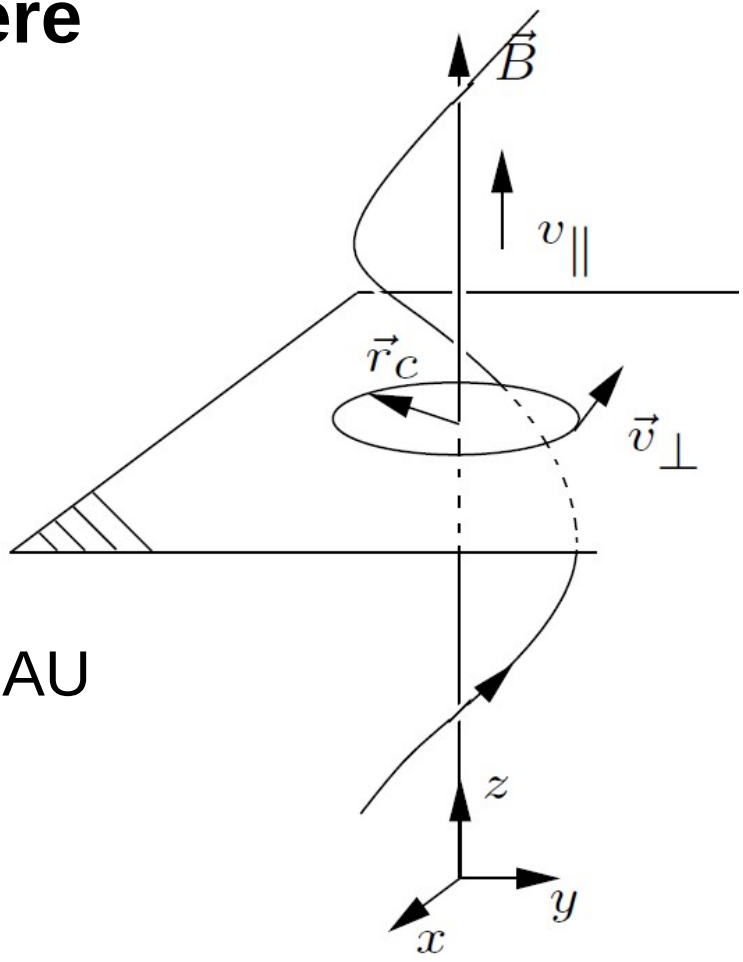
Radiation Transport in the Heliosphere

Electrically charged ions and electrons

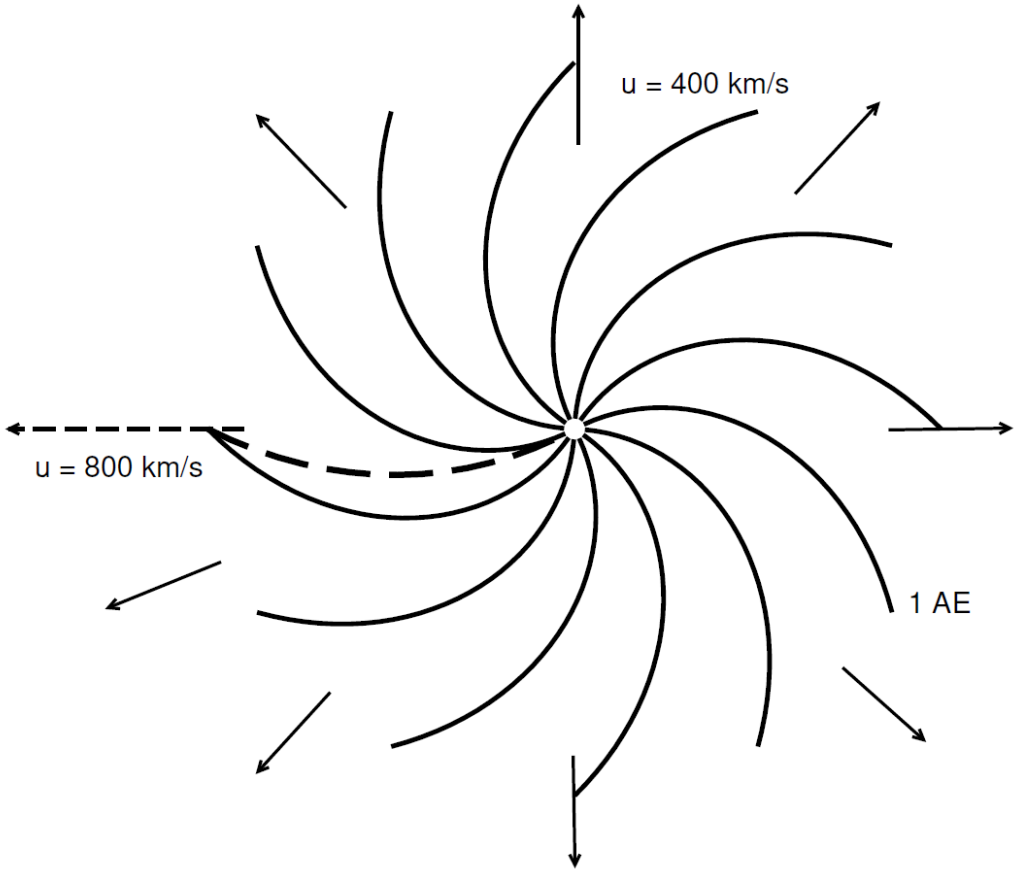
$$r_c = \frac{|p_\perp|}{q\,B}$$

Interplanetary magnetic field controls propagation

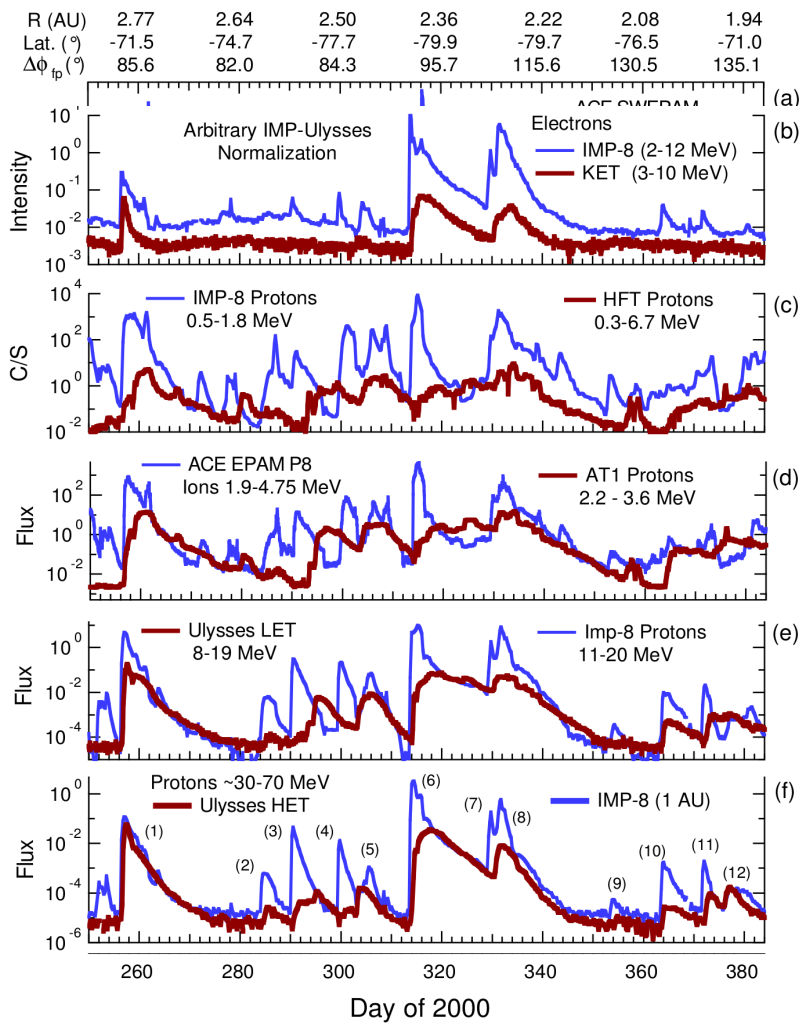


For a 1 MeV proton at 1 AU
r_c is nearly 30,000 km

Radiation Transport in the Heliosphere



- The solar wind pulls the magnetic into the heliosphere.
- Solar rotation leads to the formation of a spiral structure of the interplanetary magnetic field (IMF).
- We call this Parker spiral
- So we expect to see energetic particles on field lines which are magnetically connected to their acceleration site.



Radiation Transport in the Heliosphere

Blue: 1AU
Red: Ulysses (see above)
How does the Sun fill the heliosphere with energetic particles?

Note how the decay phases are all very similar.

This indicates that a large 'reservoir' of energetic particles that fills the heliosphere is being depleted at the same rate everywhere.

How is it filled?
Why does it empty in lockstep?
Measurements close to Sun!

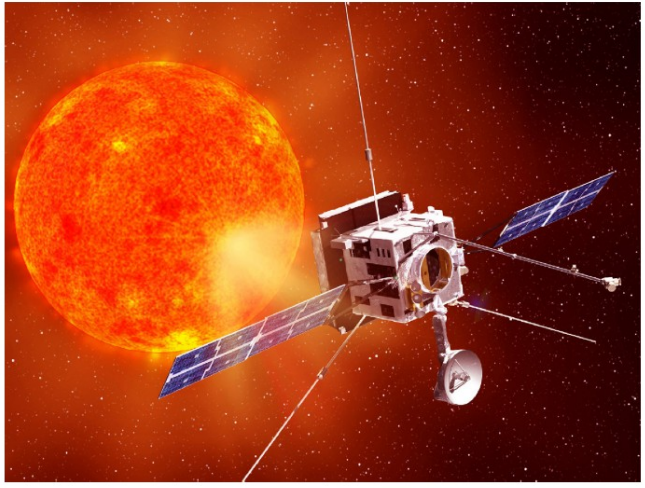
How do solar eruptions produce energetic particle radiation that fills the heliosphere?

esa

ESA/SRE(2011)14
July 2011

Solar Orbiter

Exploring the Sun-heliosphere connection



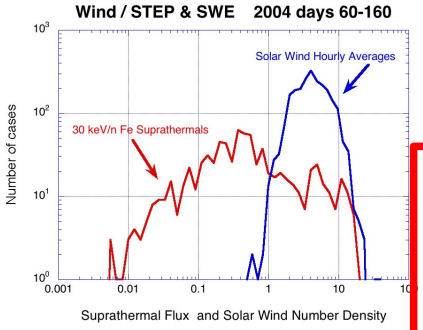
Definition Study Report

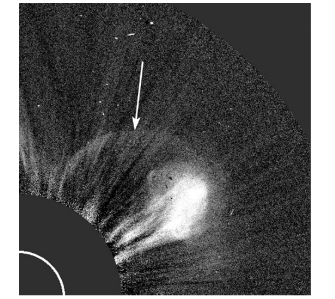
1) How and where are energetic particles accelerated at the Sun?

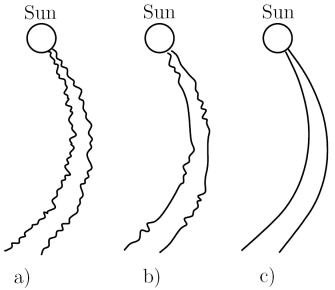
2) How are energetic particles released from their sources and distributed in space and time?

3) What are the seed populations for energetic particles?

To be an energetic particle you need to be:







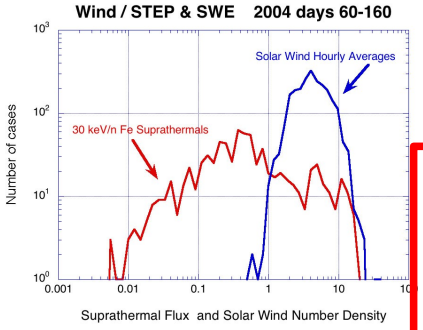
From the Solar Orbiter Red Book:

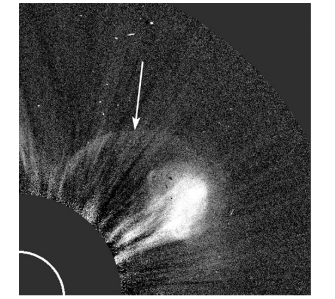
3) What are the seed populations for energetic particles?

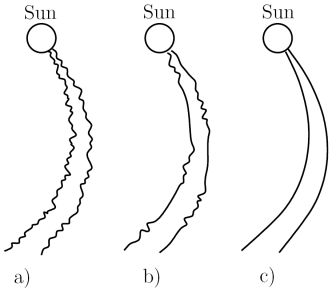
1) How and where are energetic particles accelerated at the Sun?

2) How are energetic particles released from their sources and distributed in space and time?

To be an energetic particle you need to be:







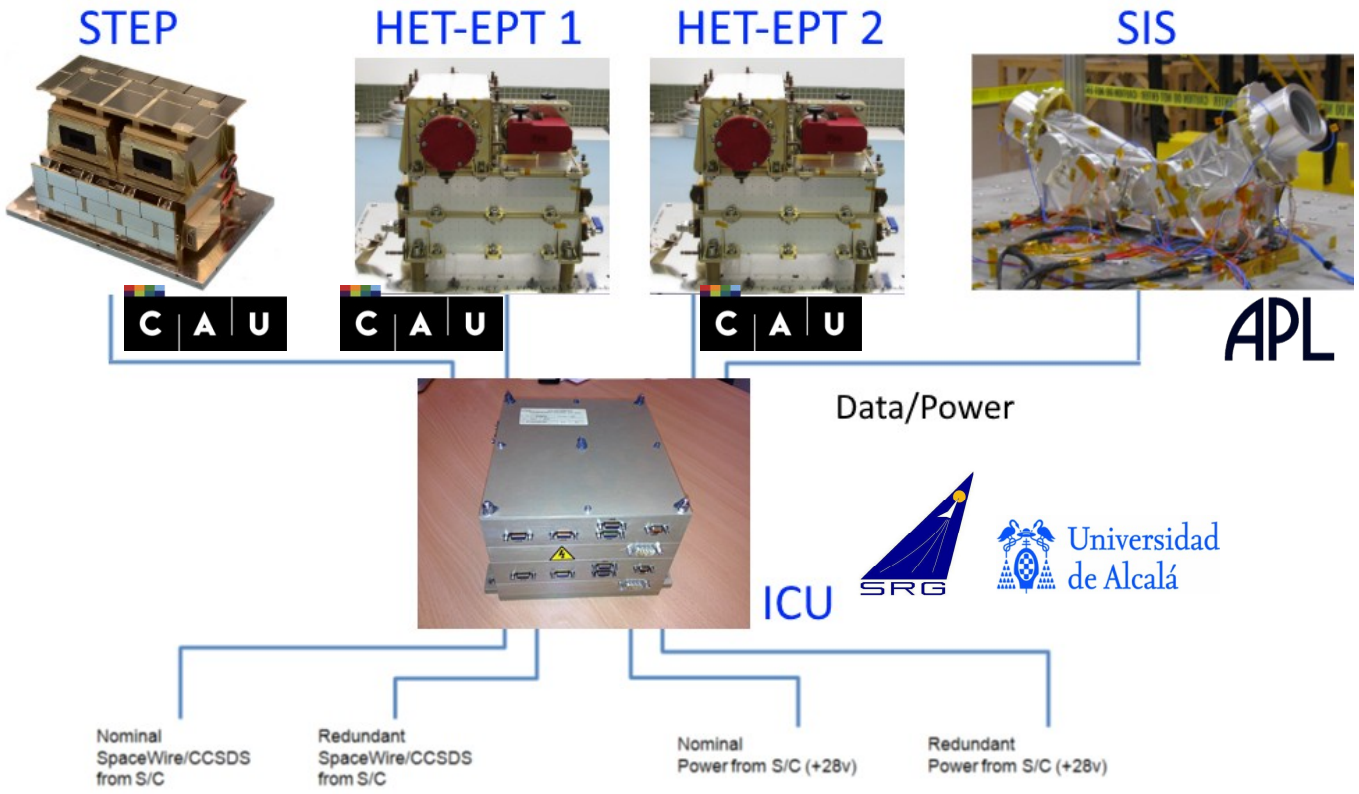
From the Solar Orbiter Red Book:

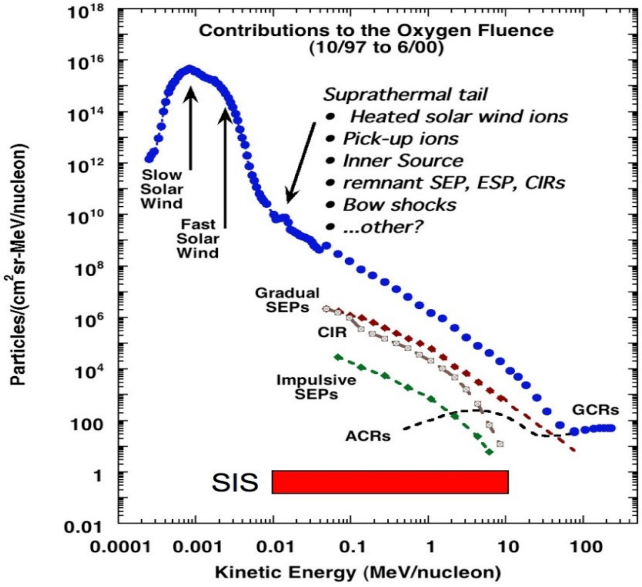
3) What are the seed populations for energetic particles? Origin not understood

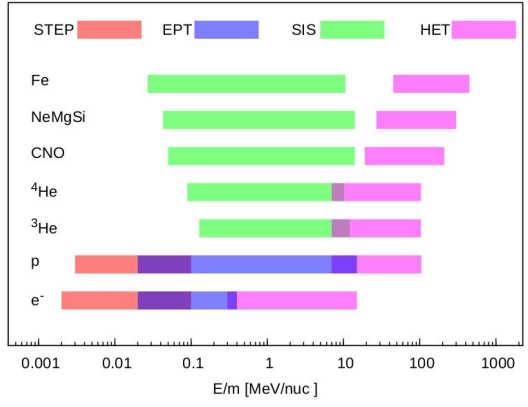
1) How and where are energetic particles accelerated at the Sun? Role of turbulence increasingly recognized

2) How are energetic particles released from their sources and distributed in space and time? Perpendicular diffusion not understood

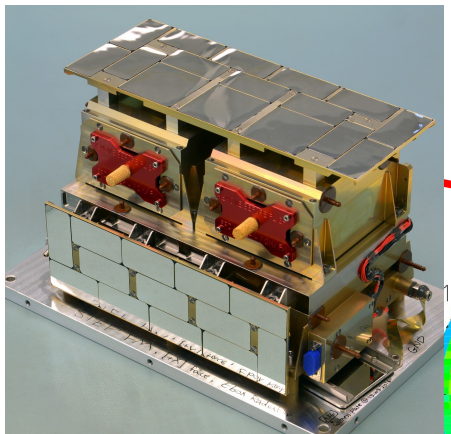
The Energetic Particle Detector (EPD)

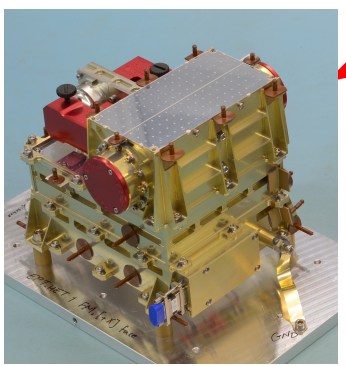


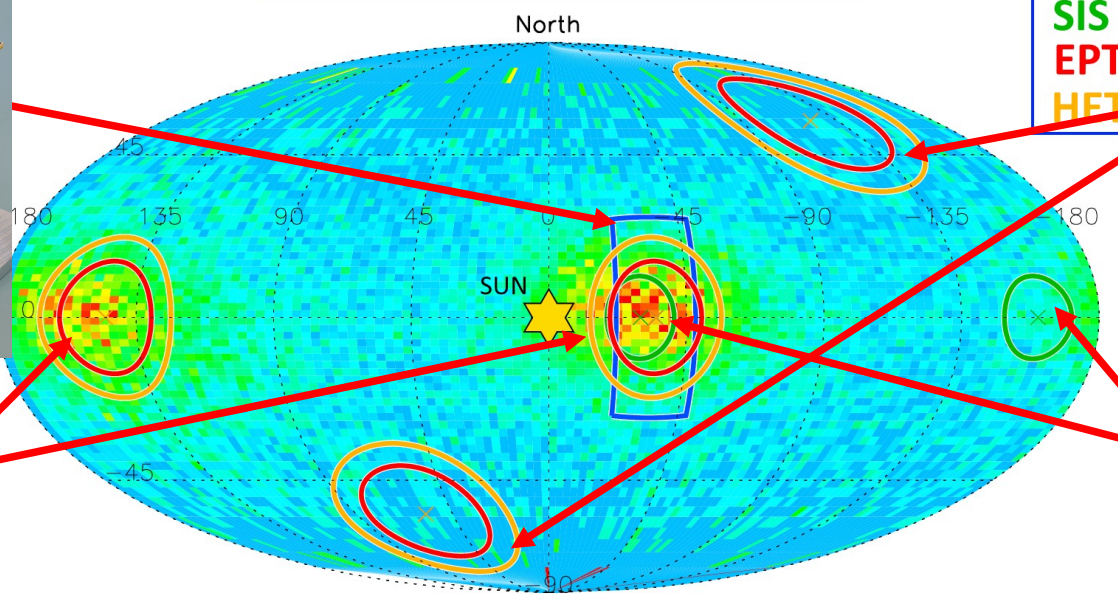




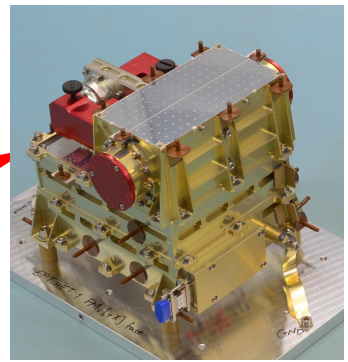
Pitch-Angle Coverage

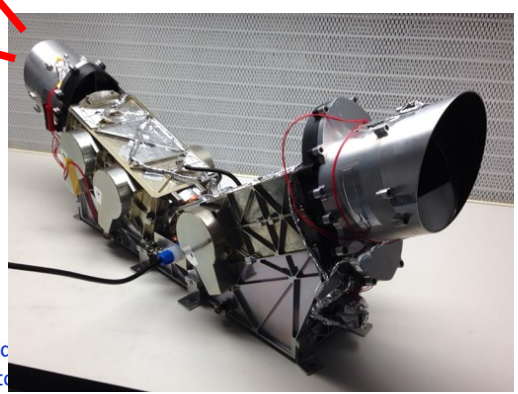






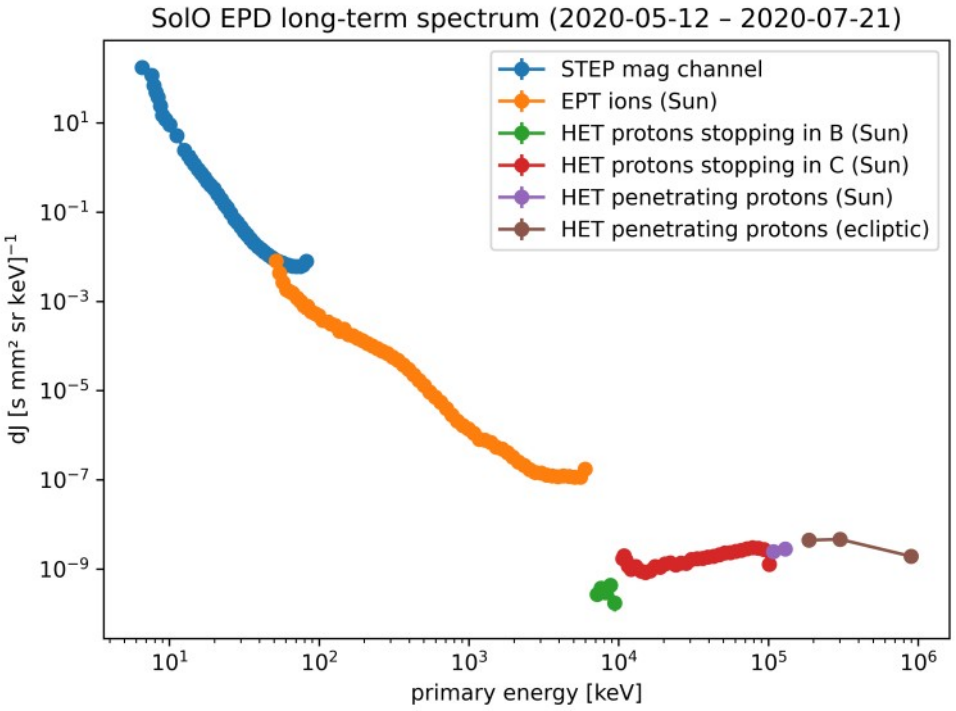
STEP*
SIS
EPT
HET



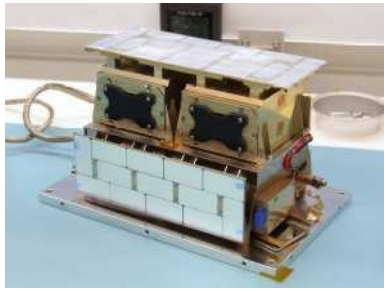


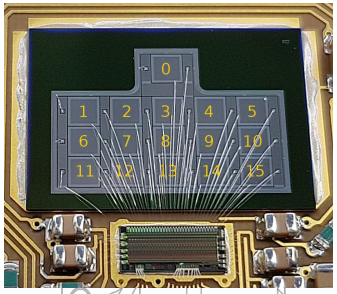
*STEP fov c
in 3x5 secto

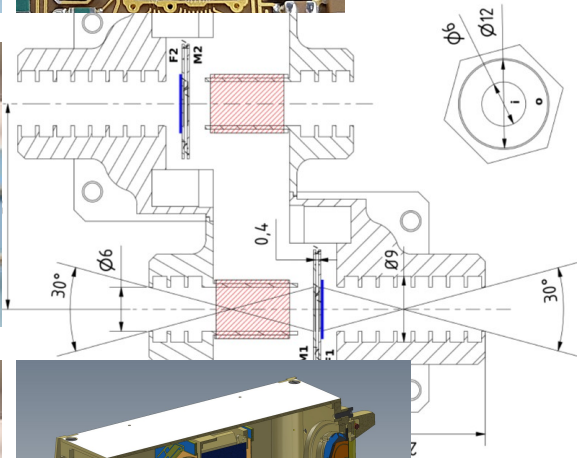
EPD & energy coverage

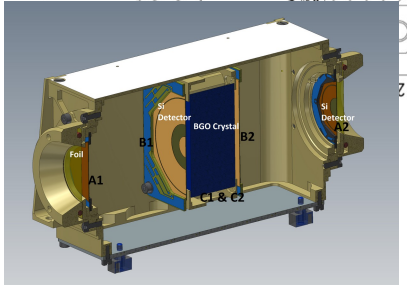


Long-term spectrum dominated by GCR



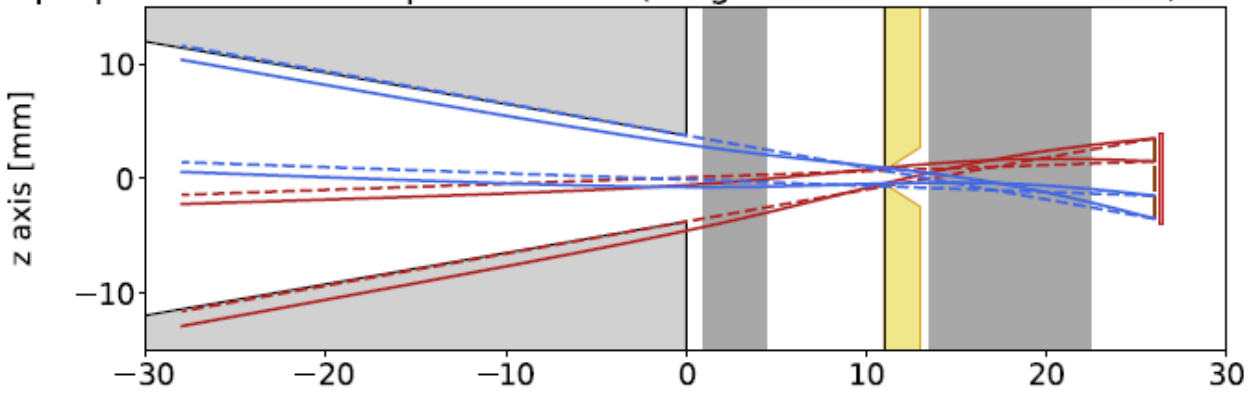




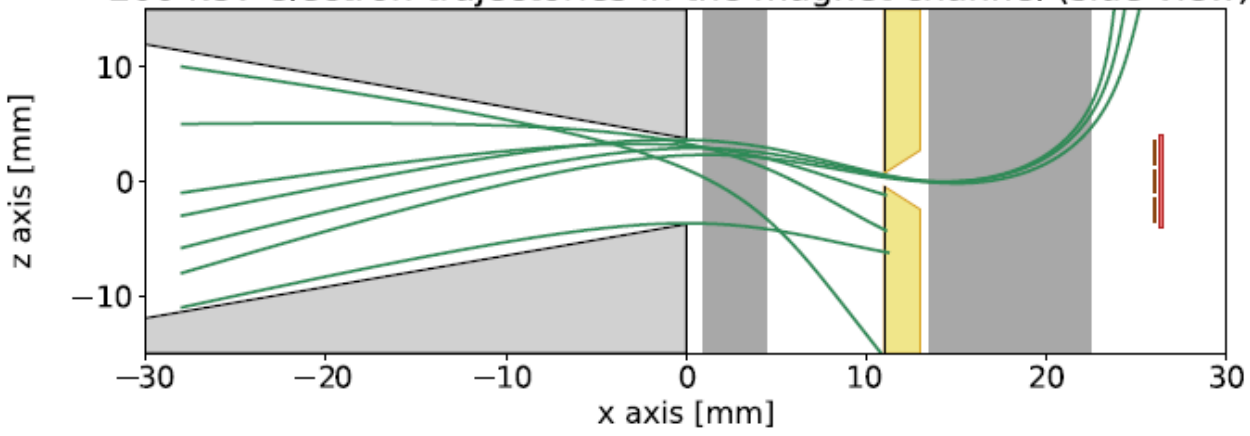


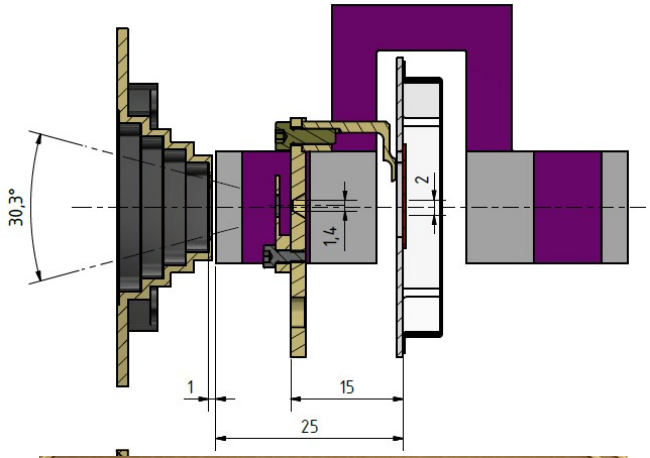
STEP measures electrons and ions

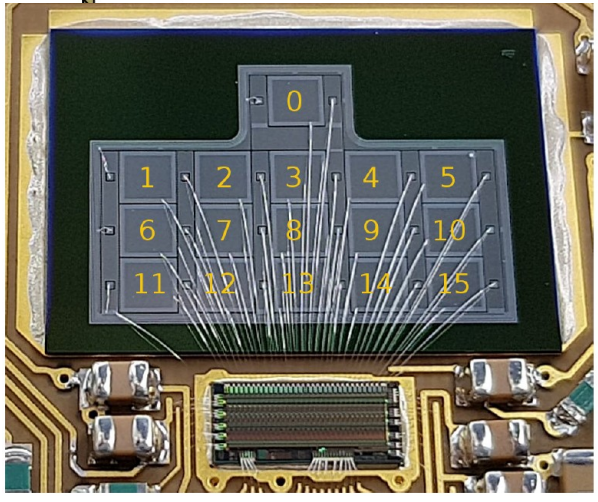
Superposition of 5 keV proton FOVs (magnet and interal channels, side view)



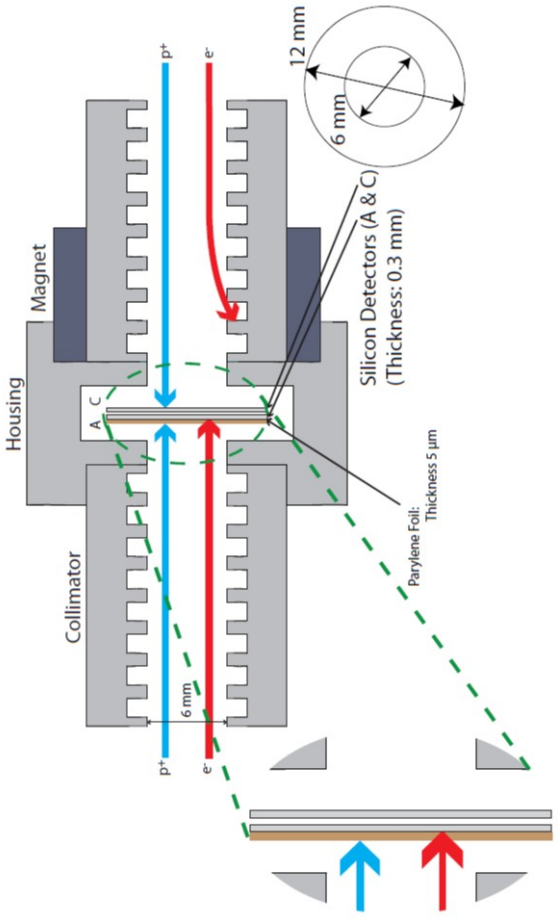
200 keV electron trajectories in the magnet channel (side view)

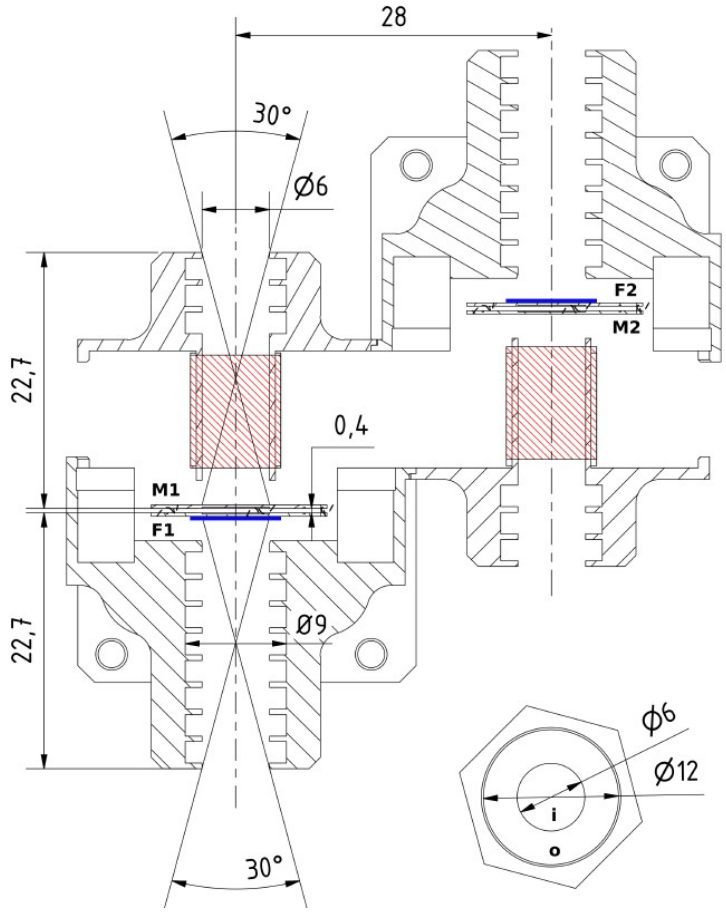


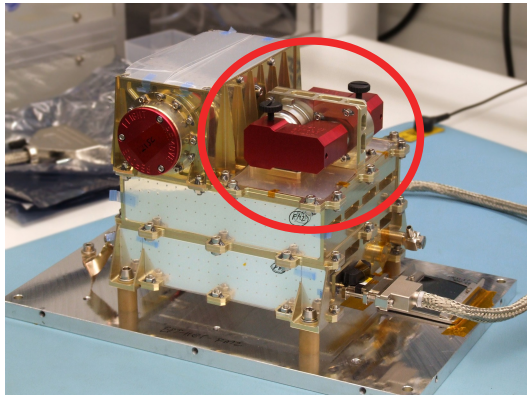


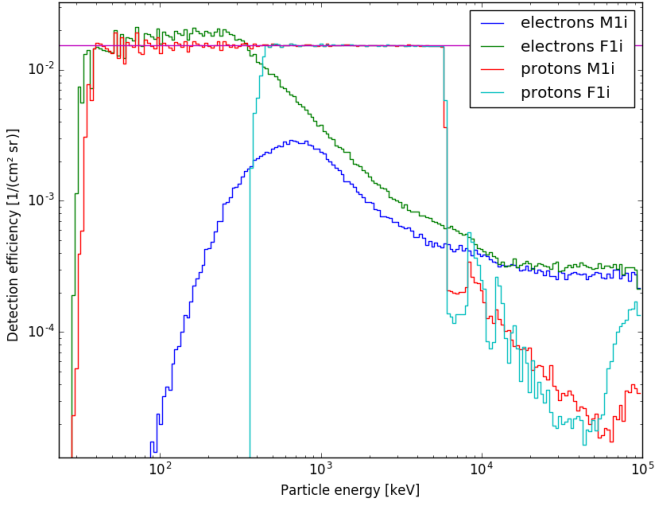


… and so does EPT









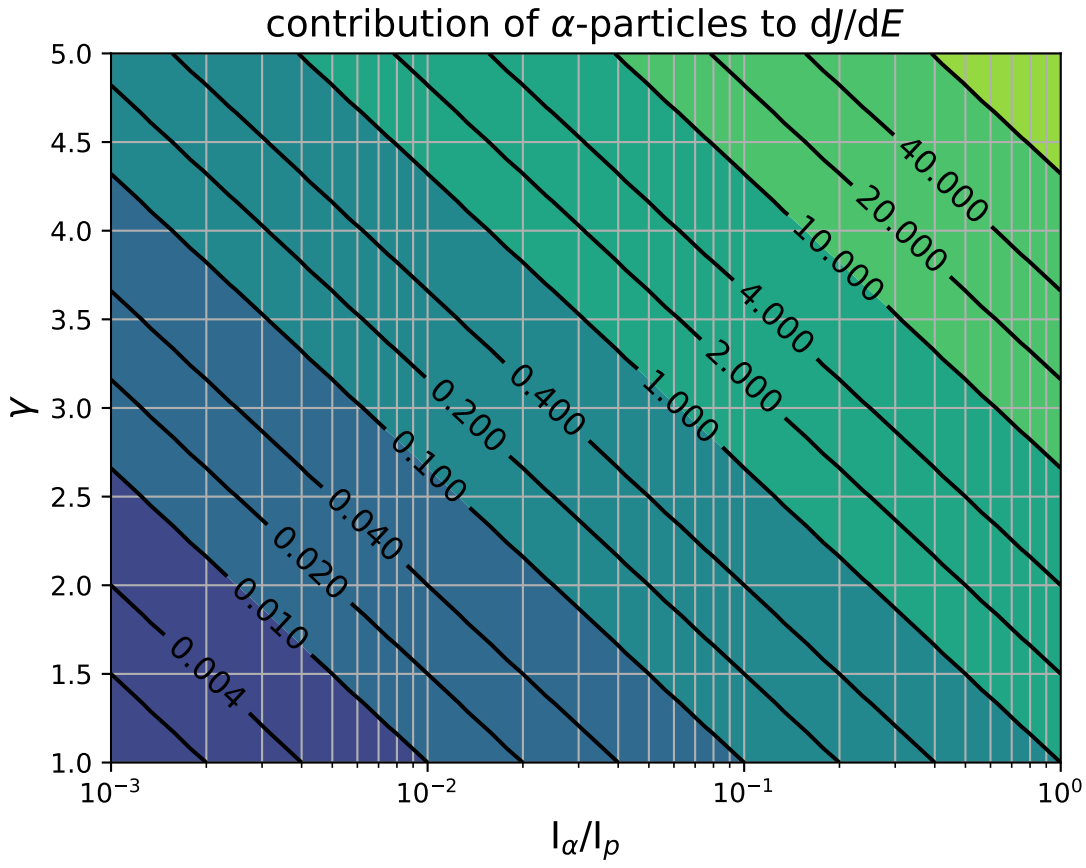
… but neither can discriminate low-energy ion species!

Assume power law for particle spectra:

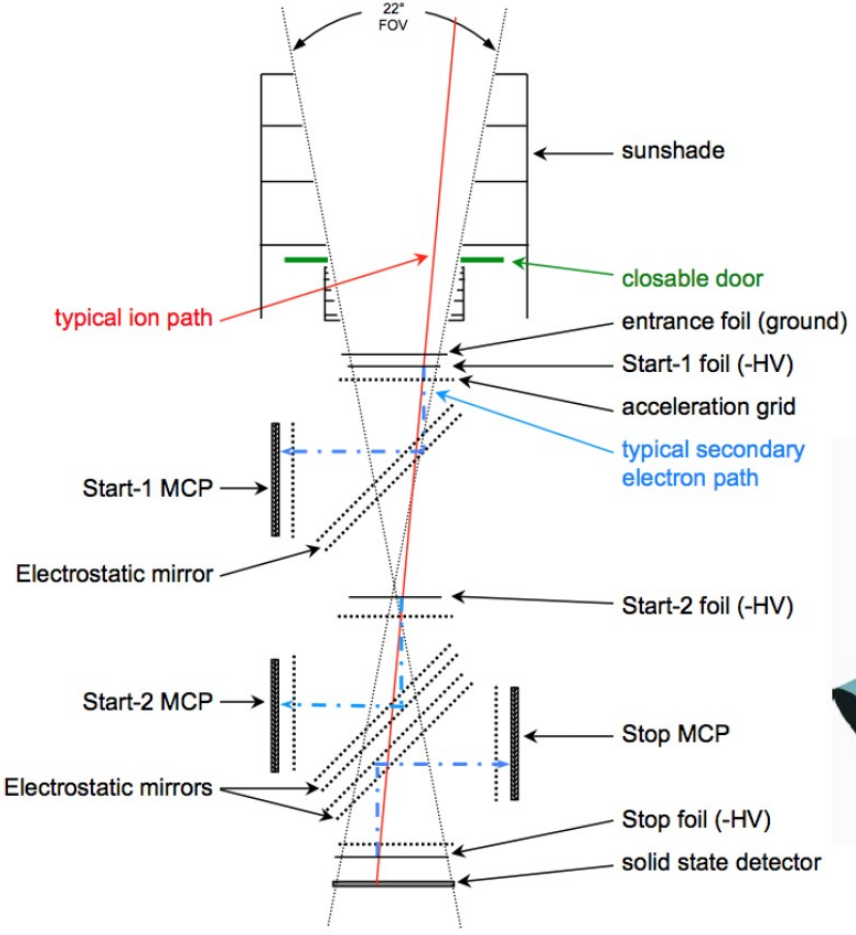
$$\frac{\mathrm{d}J}{\mathrm{d}E} = \frac{\mathrm{d}J_p}{\mathrm{d}E} + \frac{\mathrm{d}J_\alpha}{\mathrm{d}E_\alpha}.$$

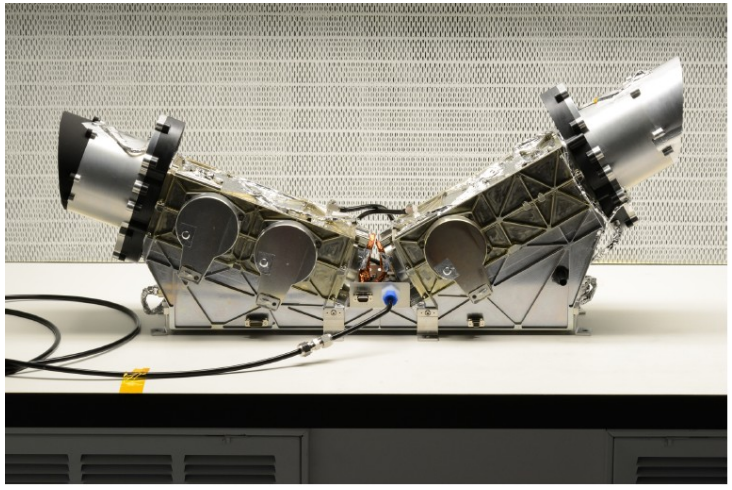
$$\frac{\mathrm{d}J_p}{\mathrm{d}E/m_p} = I_p \left(\frac{E_p}{m_p}\right)^{-\gamma}$$

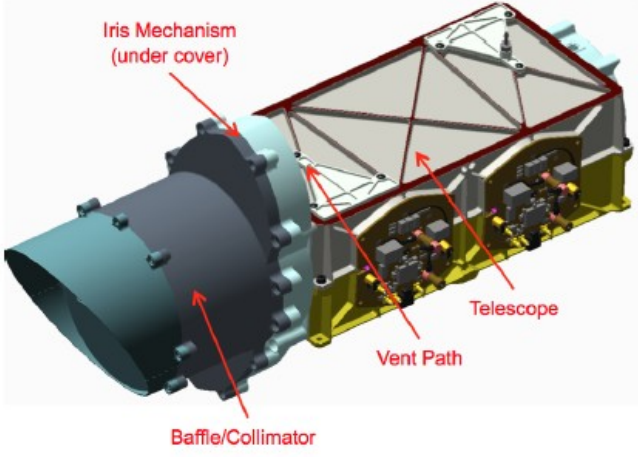
$$\frac{\mathrm{d}J}{\mathrm{d}E} = I_p E^{-\gamma}\left(1+f\right),$$

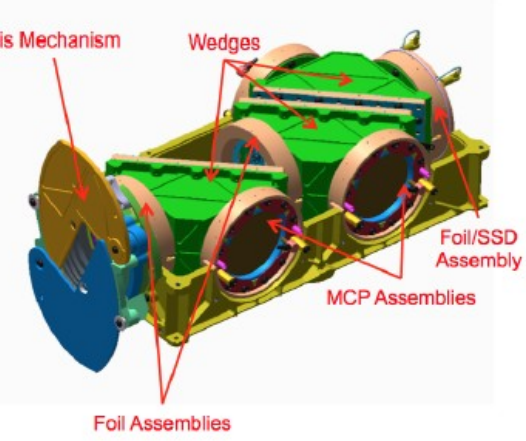


… but SIS can!

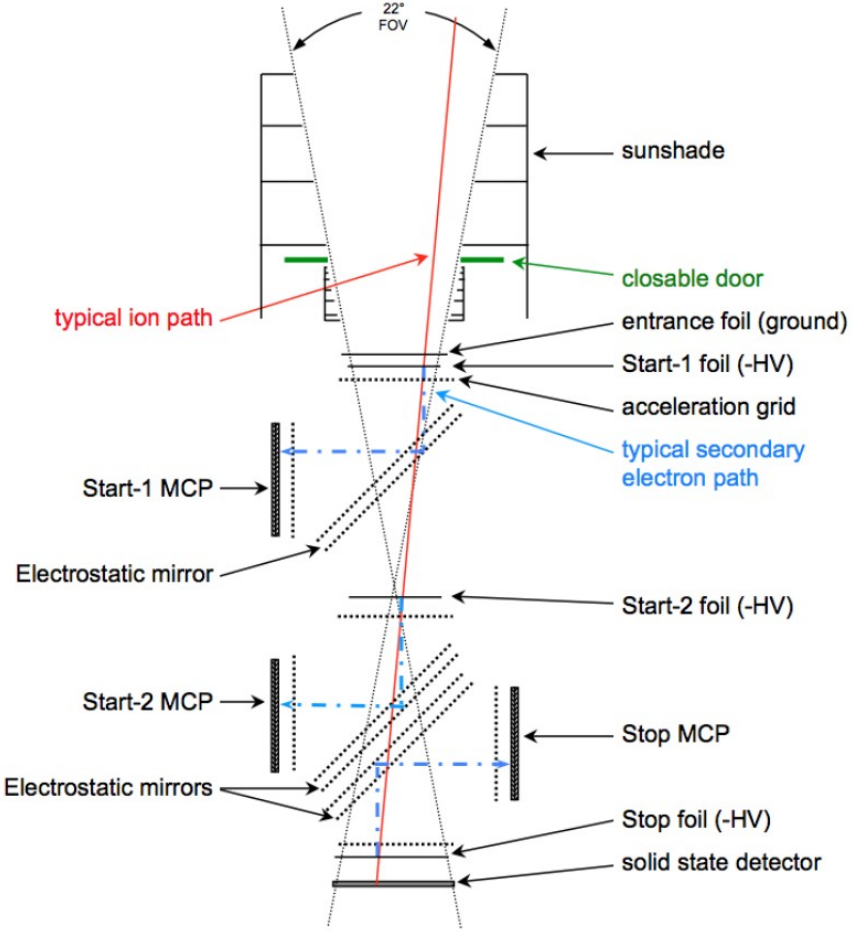

22°
FOV
sunshade
closable door
typical ion path
entrance foil (ground)
Start-1 foil (-HV)
acceleration grid
typical secondary
electron path
Start-1 MCP
Electrostatic mirror
Start-2 foil (-HV)
Start-2 MCP
Stop MCP
Electrostatic mirrors
Stop foil (-HV)
solid state detector

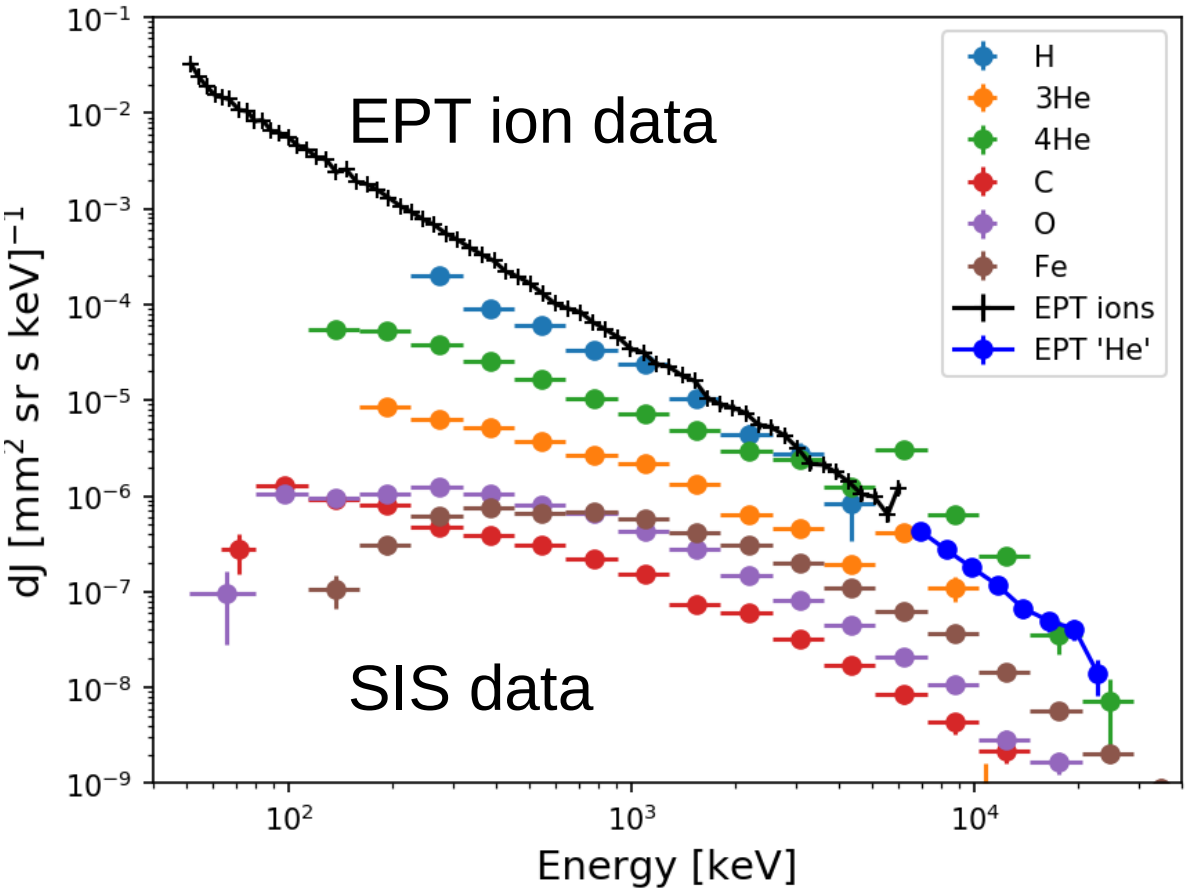



Iris Mechanism
(under cover)
Telescope
Vent Path
Baffle/Collimator

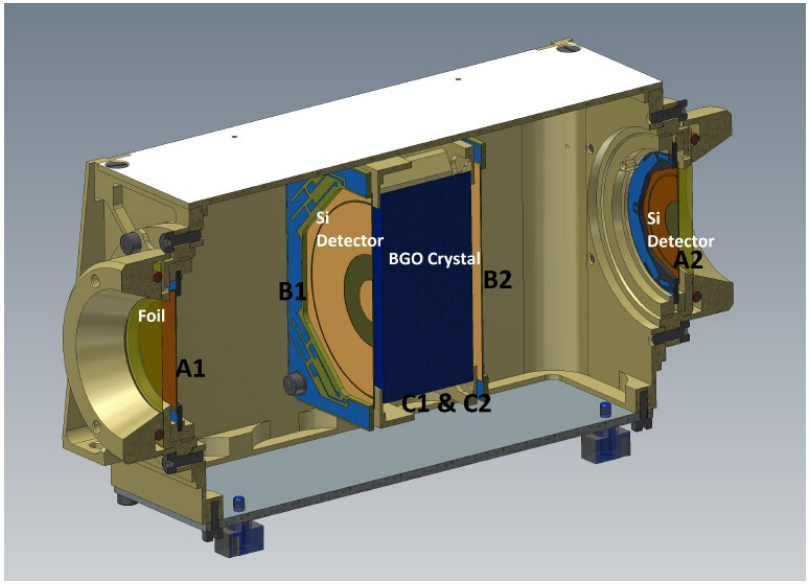

Iris Mechanism
Wedges
Foil/SSD
Assembly
MCP Assemblies
Foil Assemblies

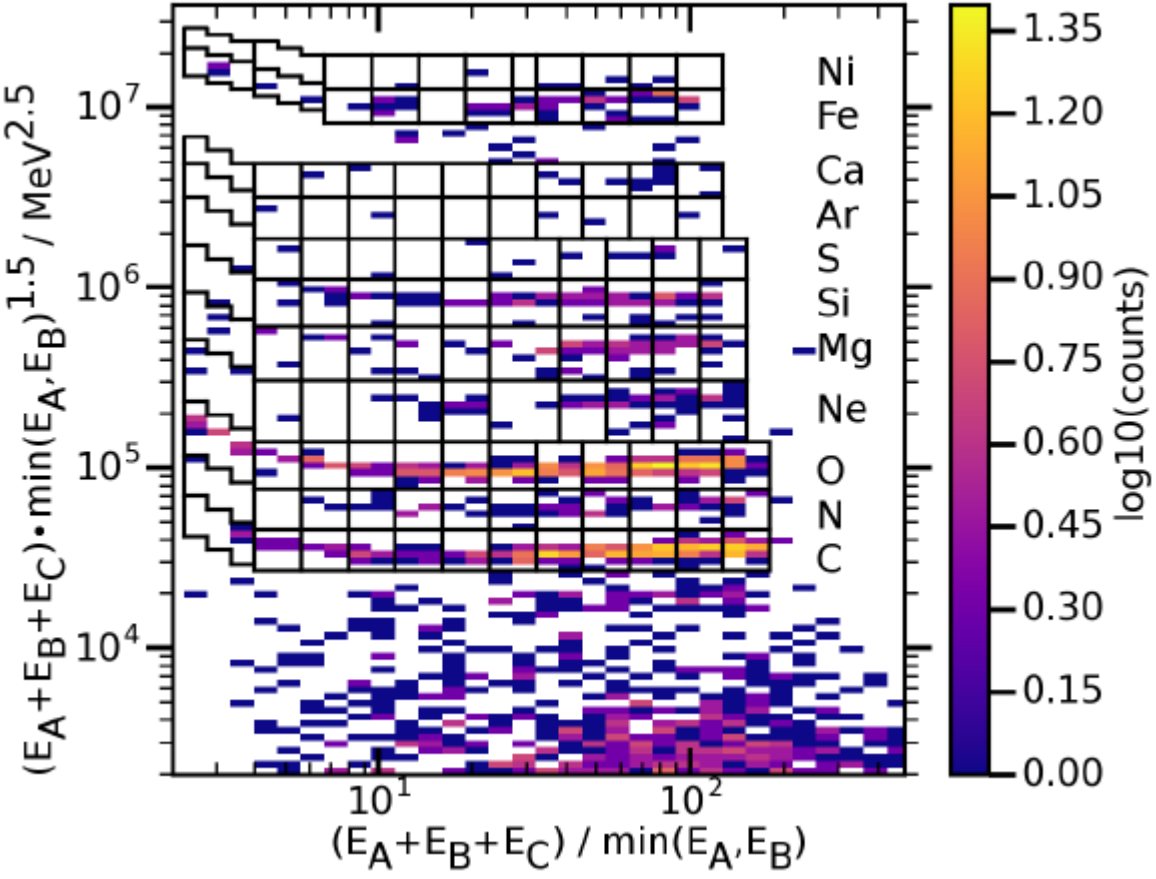
… but SIS can!


22°
FOV
sunshade
closable door
typical ion path
entrance foil (ground)
Start-1 foil (-HV)
acceleration grid
typical secondary
electron path
Start-1 MCP
Electrostatic mirror
Start-2 foil (-HV)
Start-2 MCP
Stop MCP
Electrostatic mirrors
Stop foil (-HV)
solid state detector


EPT ion data
SIS data
H
3He
4He
C
O
Fe
EPT ions
EPT 'He'
dJ [mm² sr s keV]⁻¹
Energy [keV]
10⁻¹
10⁻²
10⁻³
10⁻⁴
10⁻⁵
10⁻⁶
10⁻⁷
10⁻⁸
10⁻⁹
10²
10³
10⁴

As can HET


Si
Detector
BGO Crystal
Si
Detector
A2
B1
B2
Foil
A1
C1 & C2

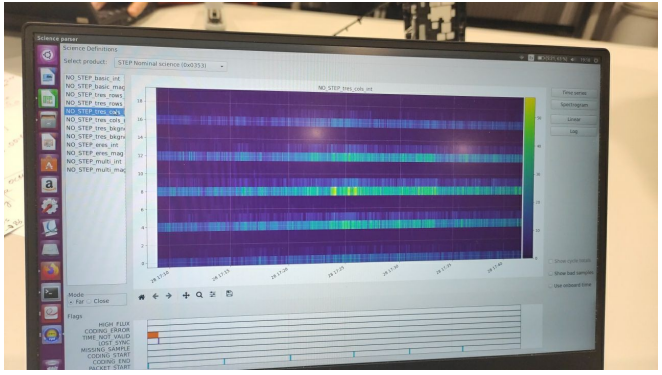

Ni
Fe
Ca
Ar
S
Si
Mg
Ne
O
N
C
10^7
10^6
10^5
10^4
10^1
10^2
$(E_A+E_B+E_C)\cdot\min(E_A,E_B)^{1.5}$ / MeV$^{2.5}$
$(E_A+E_B+E_C)$ / $\min(E_A,E_B)$
1.35
1.20
1.05
0.90
0.75
0.60
0.45
0.30
0.15
0.00
log10(counts)

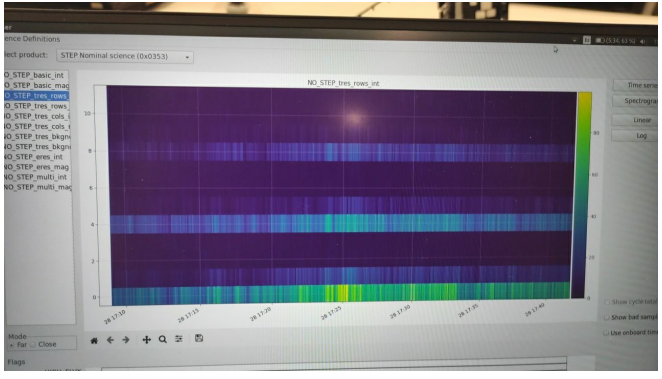
Data Products (very rough summary, see instr. paper)

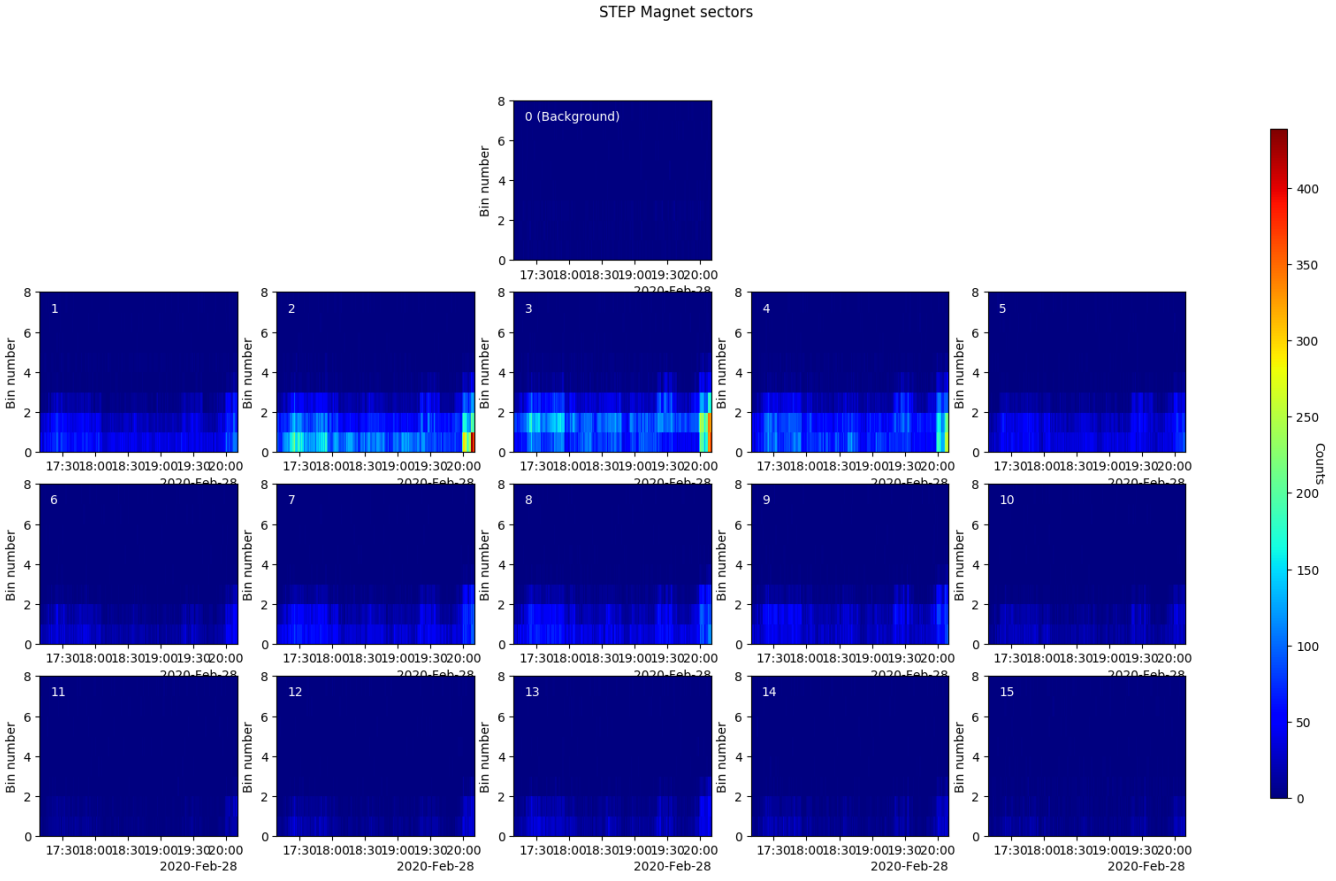
	STEP	EPT (x2)	HET (x2)
Housekeeping (some „daily“)	Voltages, currents, temperatures @ various cadences		
Low-latency („daily“)	Sum pxls @ 24 bins Sum pxls @ 1 s	8/16 bins @ 30 s (e-/p) 1/2 bins @ 5 s (e-/p)	Less E/t-resolution than nominal DPs
Nominal (< 180 days)	16 pxls @ 8 bins Various other DP	34/64 bins @ 60/5 s 17/12 bins @ 1 s	1 – 300 s Many, many DPs
Burst (up to 1 s cad.)	16 pxls @ 16 bins Sum pxls @ 48 bins	34/64 bins at 1 s pene He @ 5s	1/6/4 bins @ to 1 s 3/62/5/11 b @ 1/5 s
PHA (in nominal DP)	16 1-kB buffers	3 1-kB buffers	13 1-kB buffers

Link to instrument paper: https://doi.org/10.1051/0004-6361/201935287

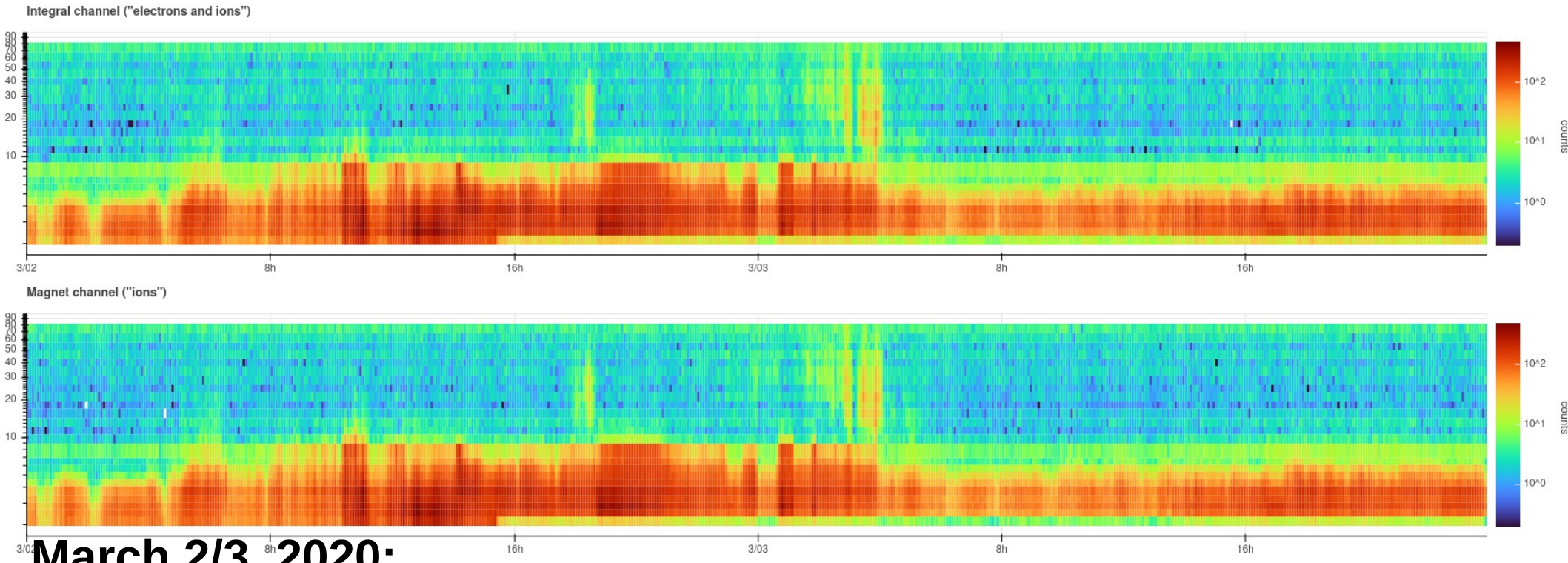
February 28, 2020: First data seen on screen at ESOC





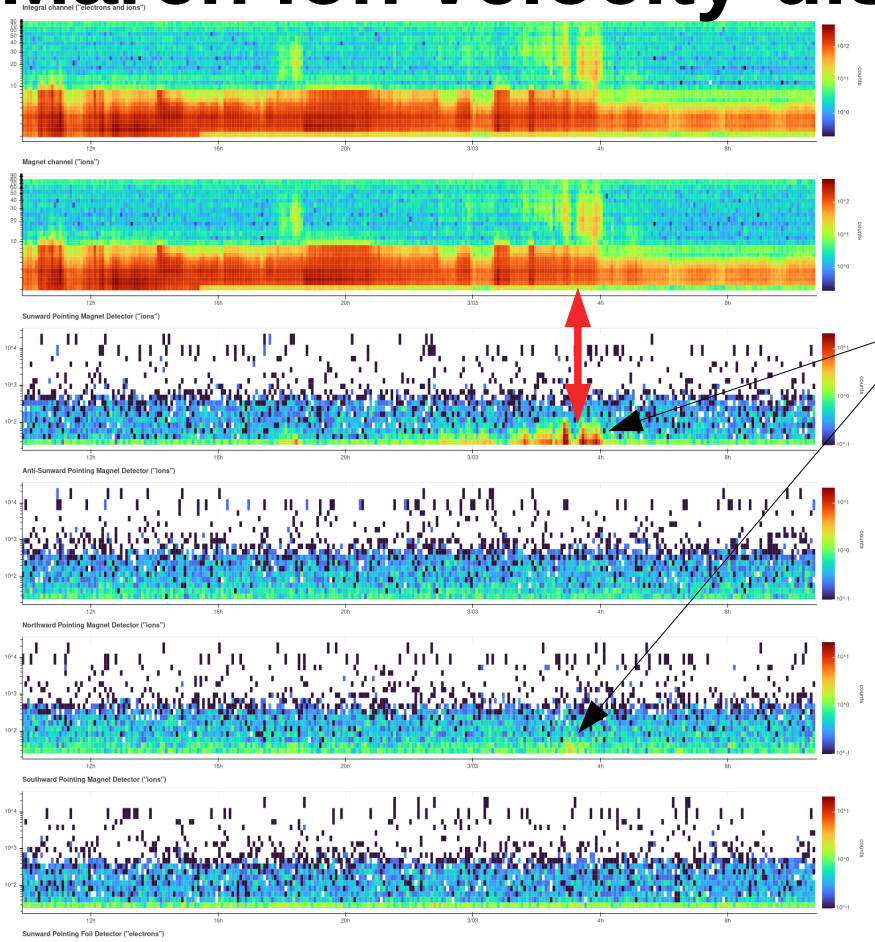


March ion velocity-dispersion events with STEP

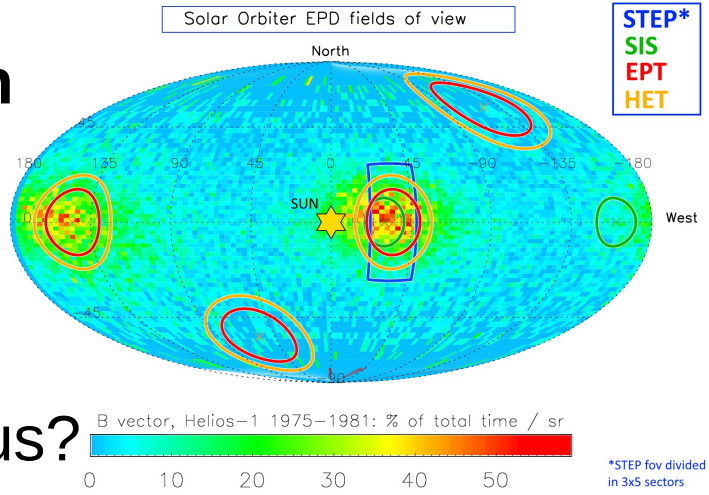


March 2/3, 2020:
Unstable „bump on tail“ distribution. Wave activity RPW/MAG?

March ion velocity-dispersion events with EPT



Also seen with EPT at low energies.

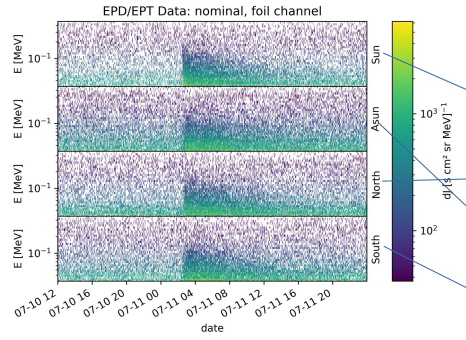


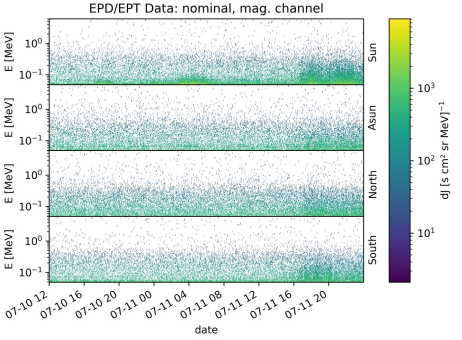
What does anisotropy tell us?

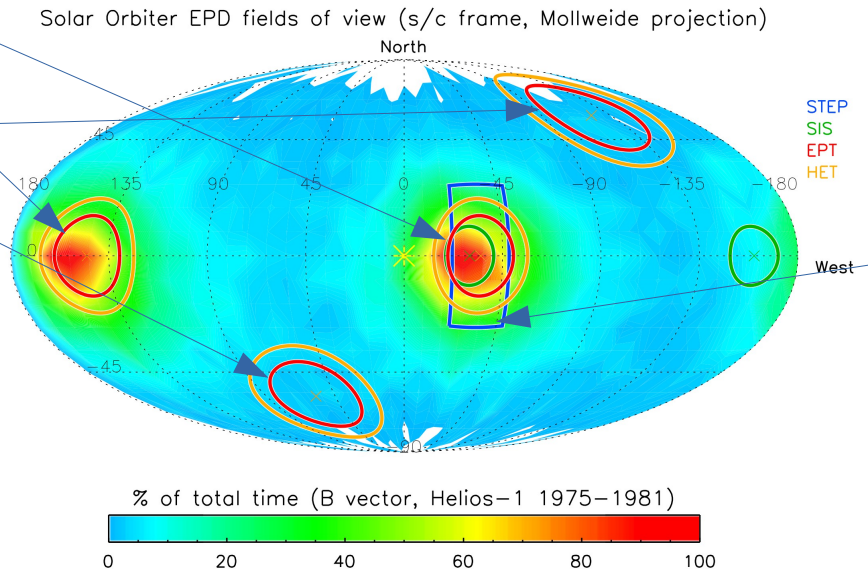
Activity not only seen in sunward telescope, but also in North telescope.

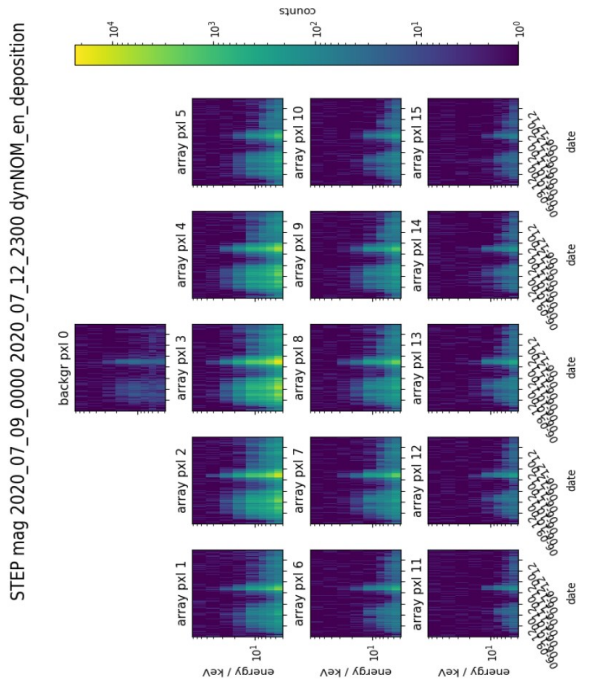
July 11, 2020 event – first electron event!

foil channel



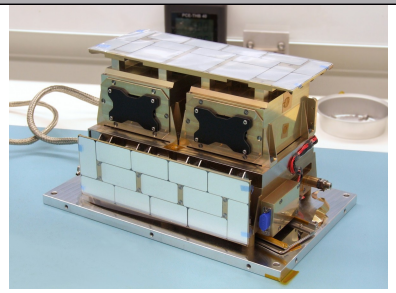




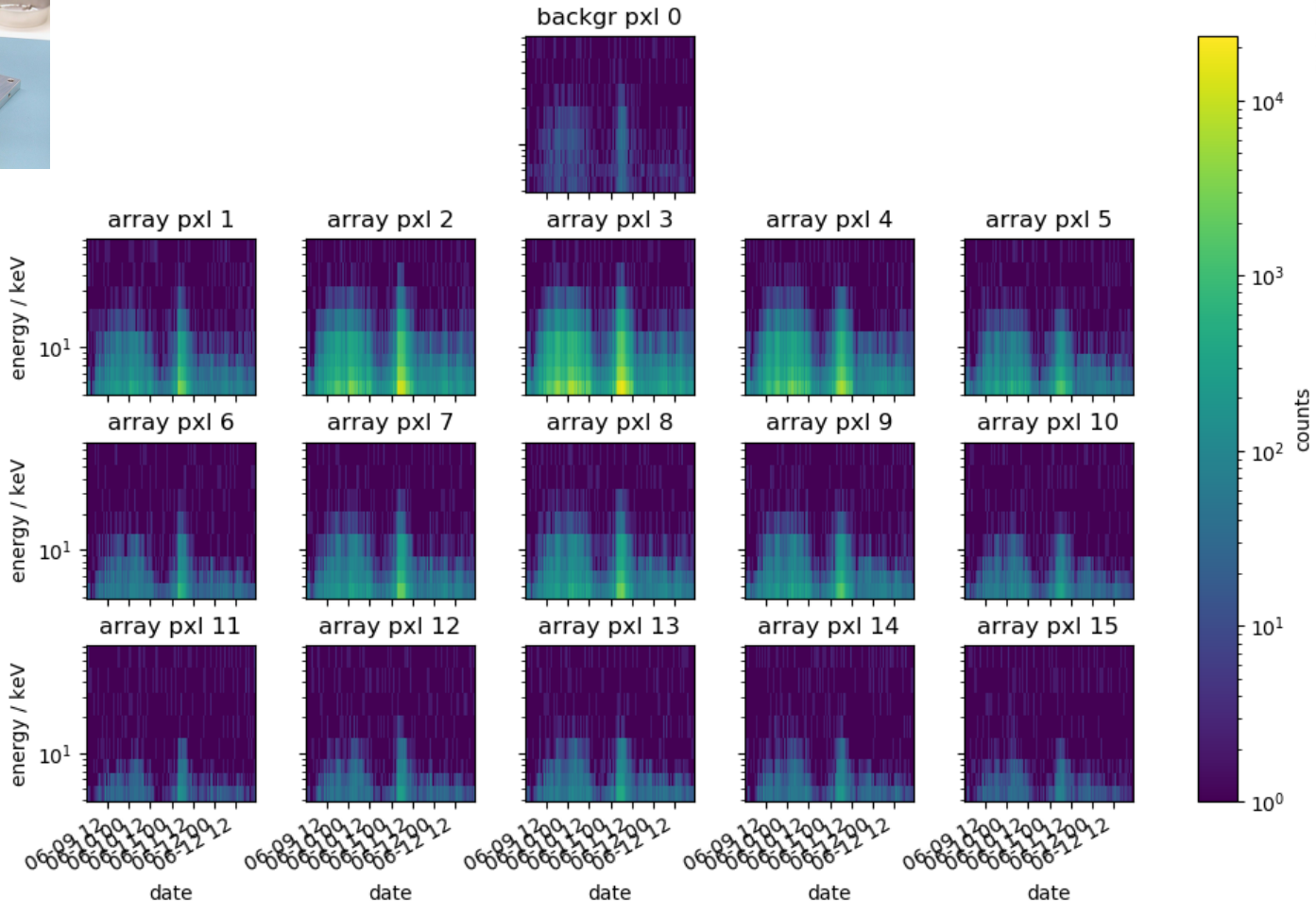


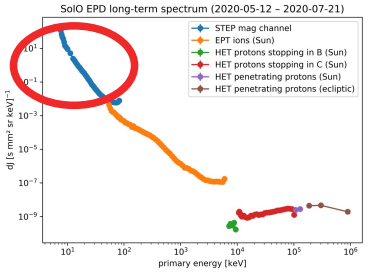
mag. channel

27 deg 35 deg 43 deg



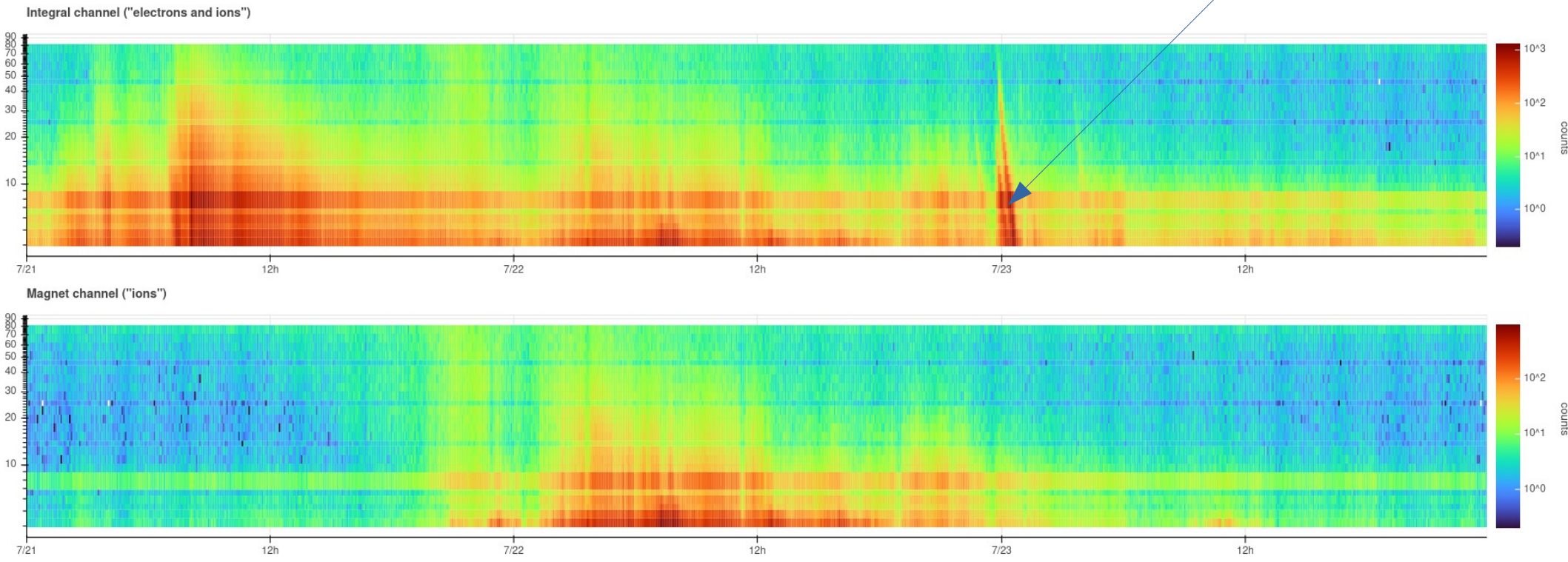
STEP mag 2020_07_09_0000 2020_07_12_2300 dynNOM_en_deposition



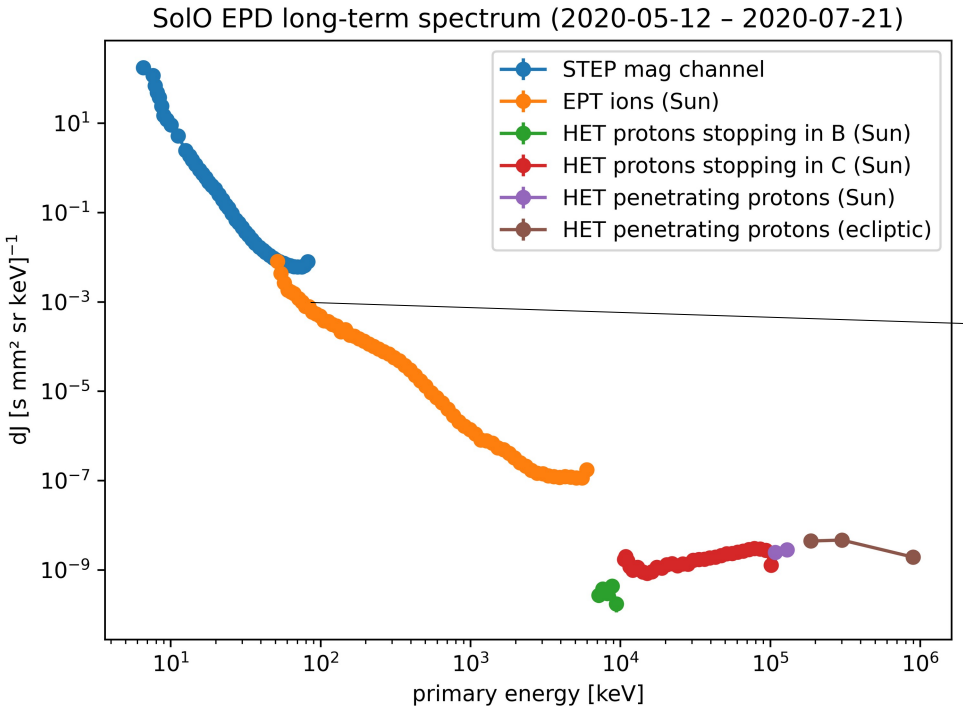


STEP data for July events: multiple electron injections

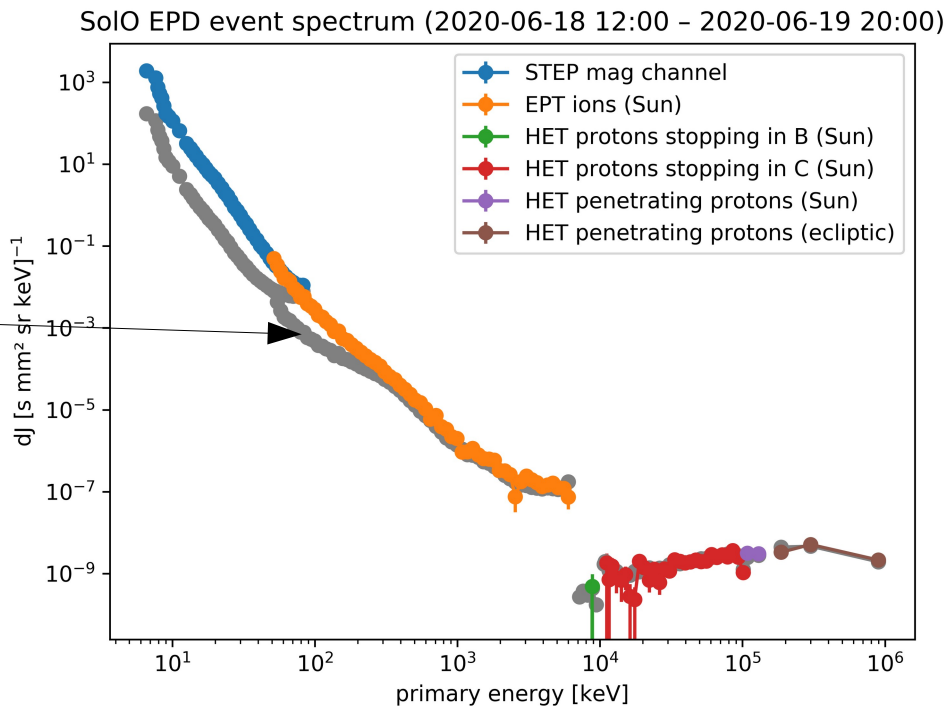
Velocity dispersion



EPD energy coverage – July 19, 2020 event

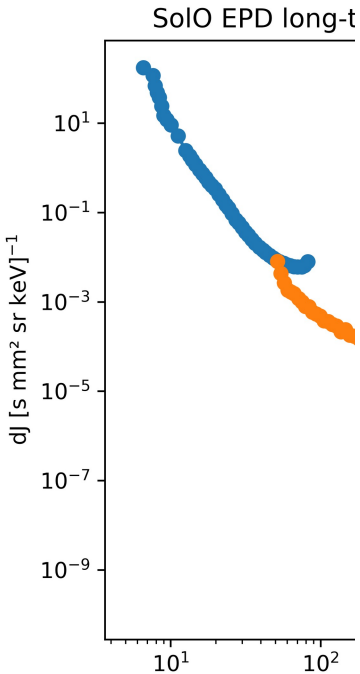


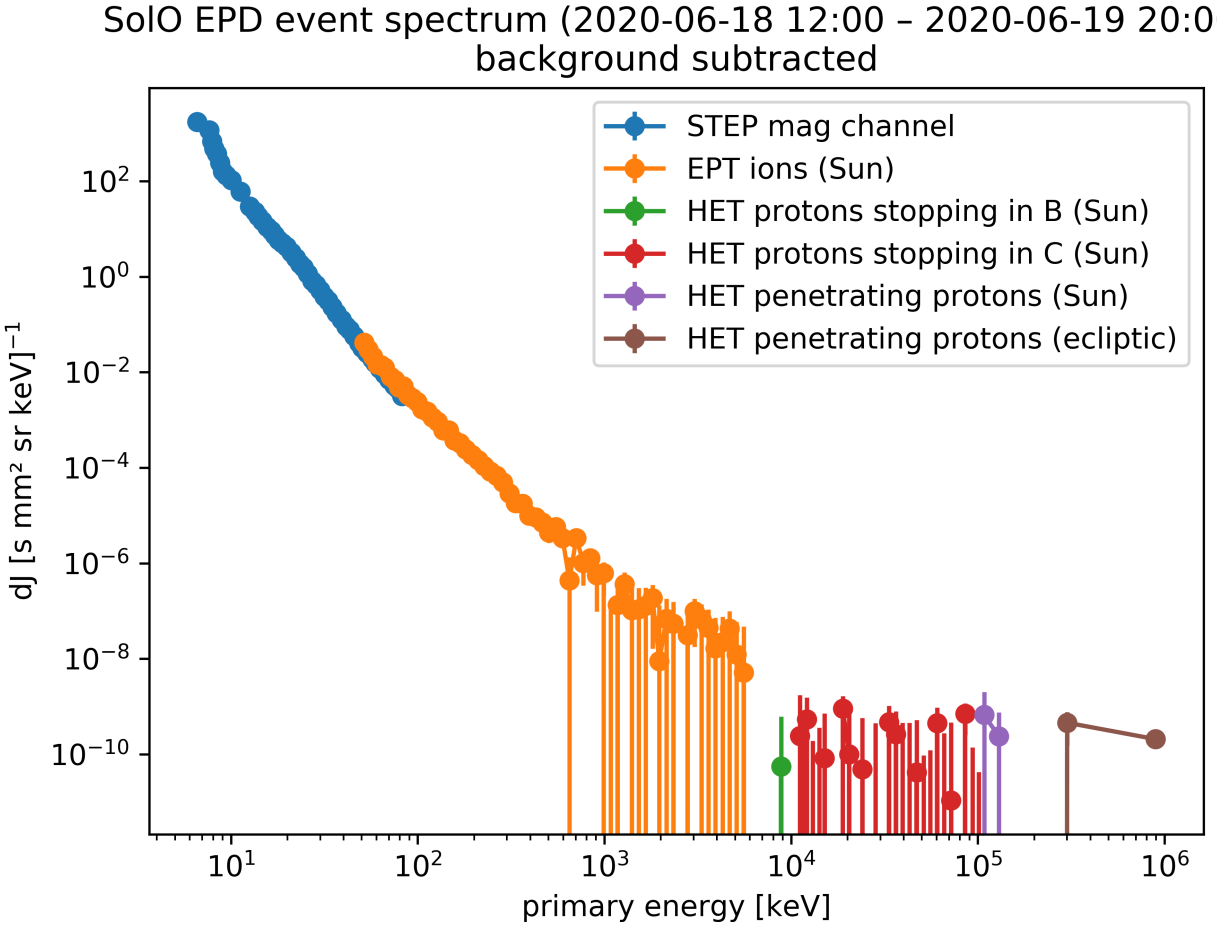
Long-term spectrum dominated by GCR

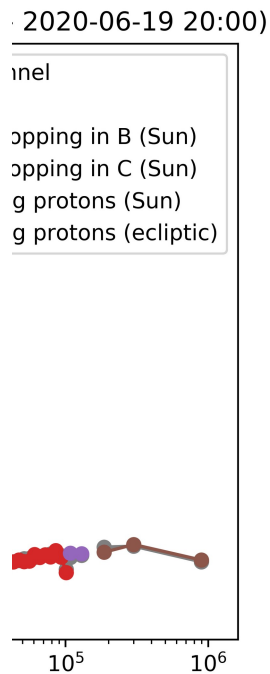


June 19, 2020 event spectrum

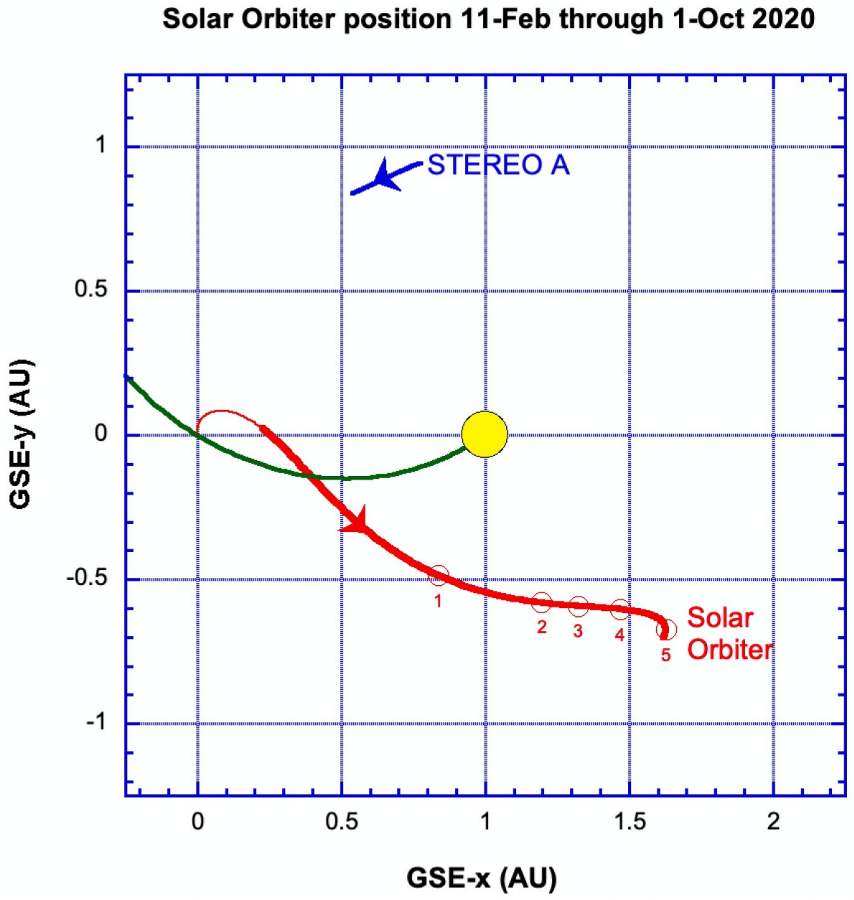
EPD energy coverage – July 19, 2020 event

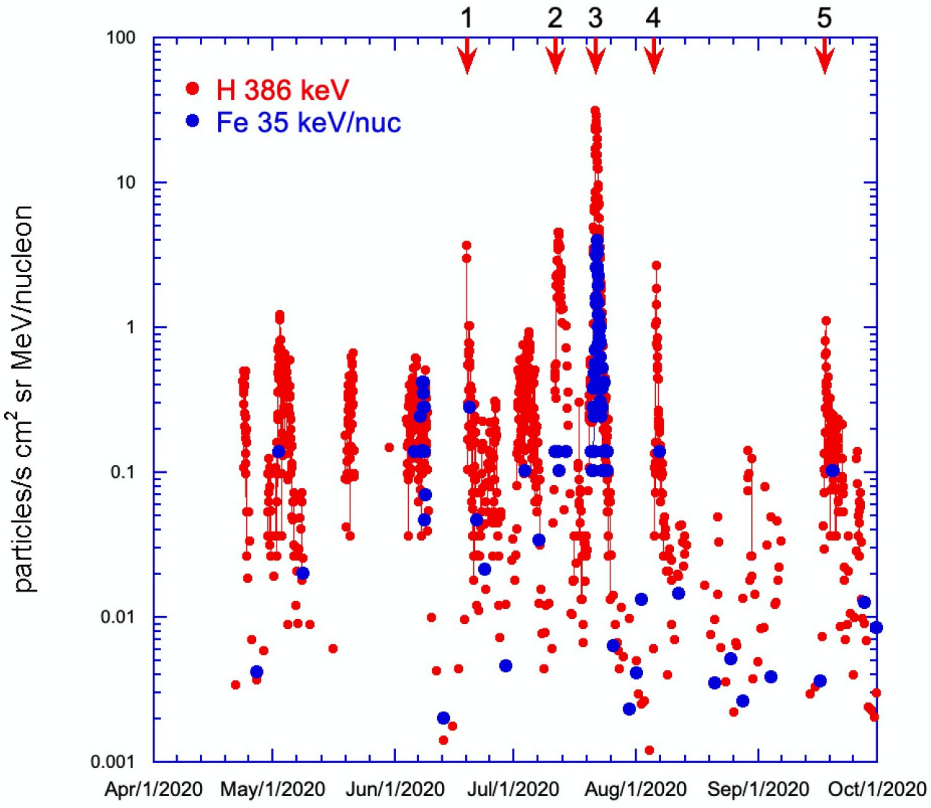


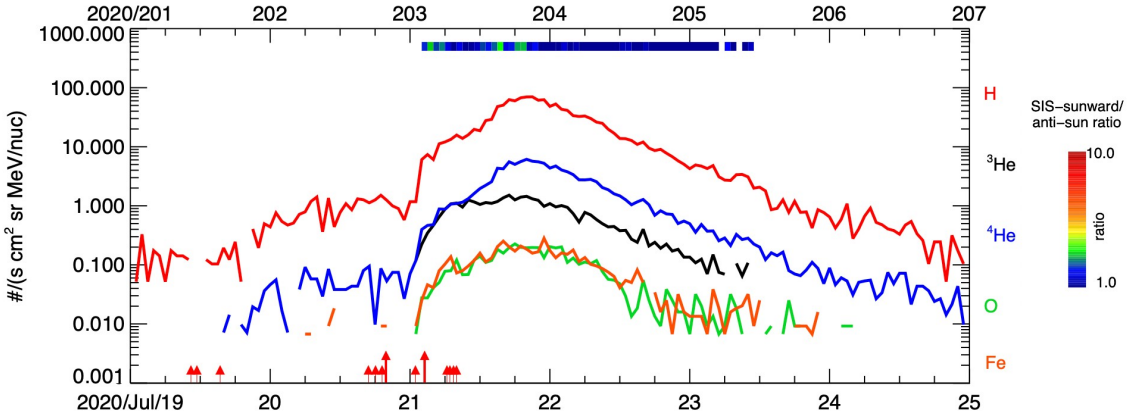


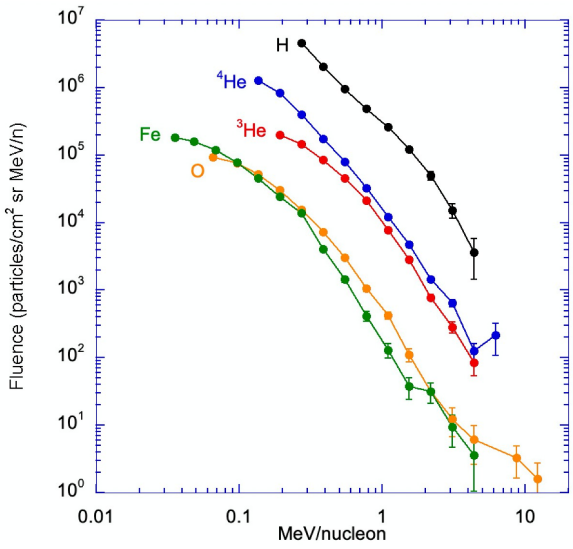


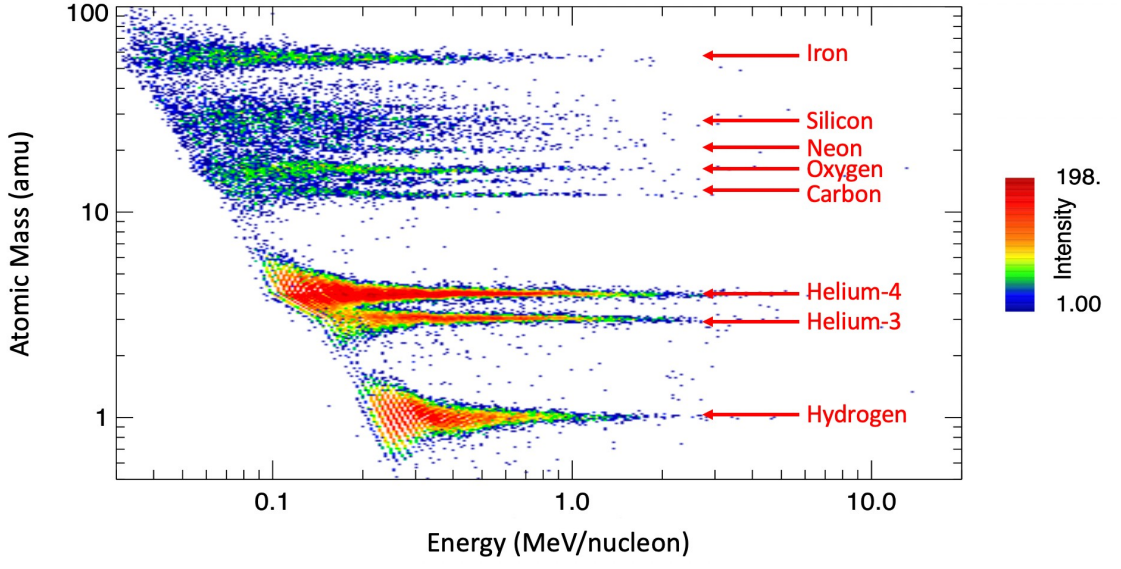
First data from SIS: CIRs and SEP events

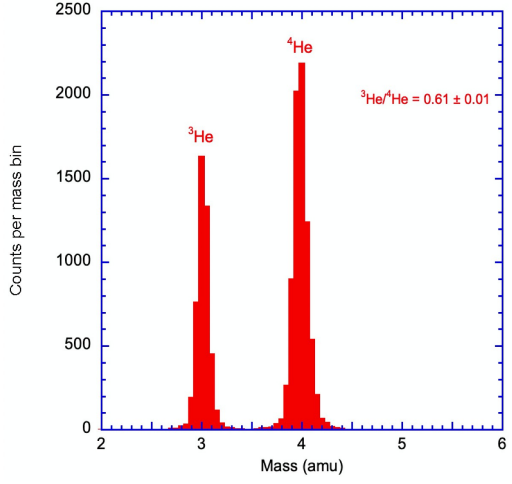




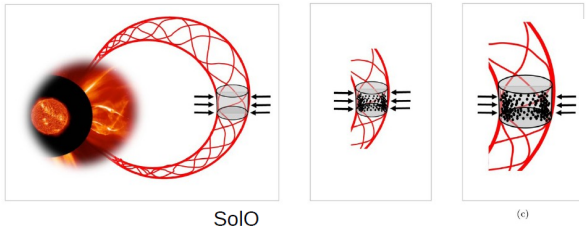

2020/201
202
203
204
205
206
207
1000.000
100.000
10.000
1.000
0.100
0.010
0.001
#/(s cm² sr MeV/nuc)
2020/Jul/19
20
21
22
23
24
25
H
³He
⁴He
O
Fe
SIS–sunward/
anti–sun ratio
10.0
ratio
1.0

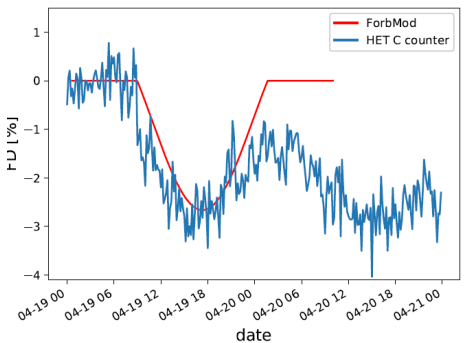

10⁷
10⁶
10⁵
10⁴
10³
10²
10¹
10⁰
Fluence (particles/cm² sr MeV/n)
H
⁴He
³He
Fe
O
0.01
0.1
1
10
MeV/nucleon

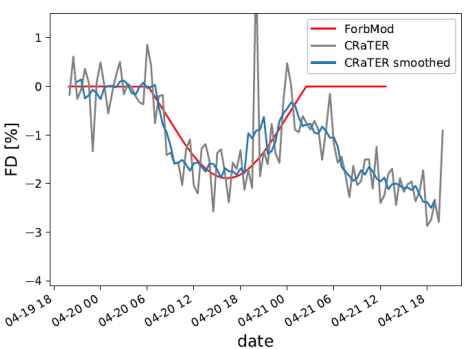

100
10
1
Atomic Mass (amu)
Iron
Silicon
Neon
Oxygen
Carbon
Helium-4
Helium-3
Hydrogen
198.
Intensity
1.00
0.1
1.0
10.0
Energy (MeV/nucleon)

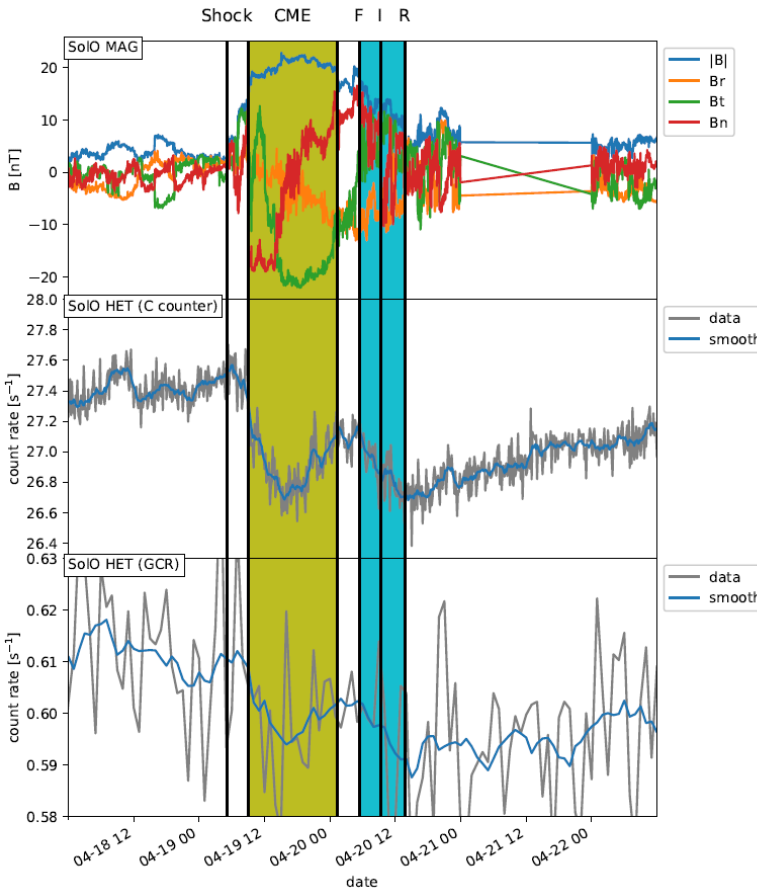

2500
2000
1500
1000
500
0
Counts per mass bin
⁴He
³He
³He/⁴He = 0.61 ± 0.01
2
3
4
5
6
Mass (amu)

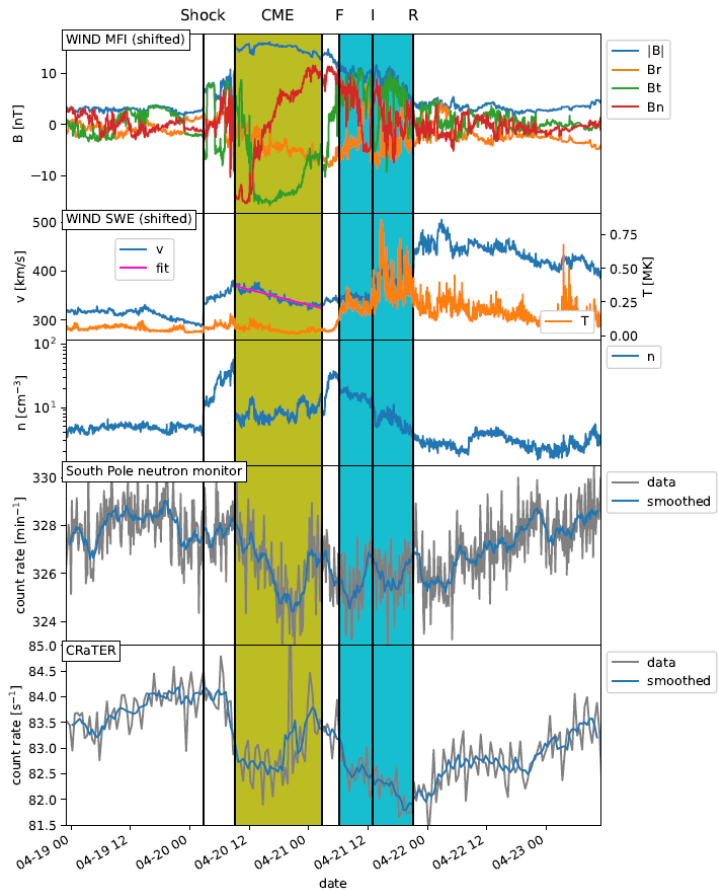
HET – Forbush decrease due to April 20 CME





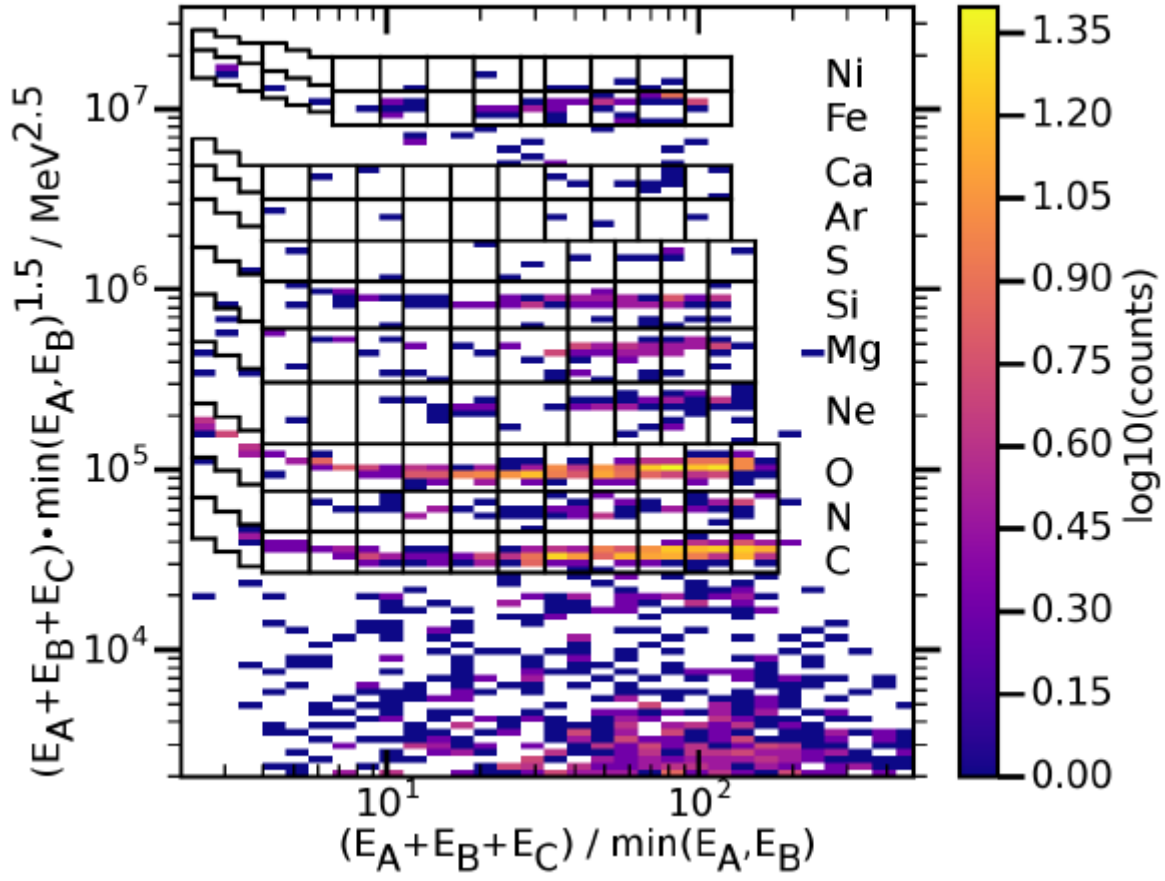


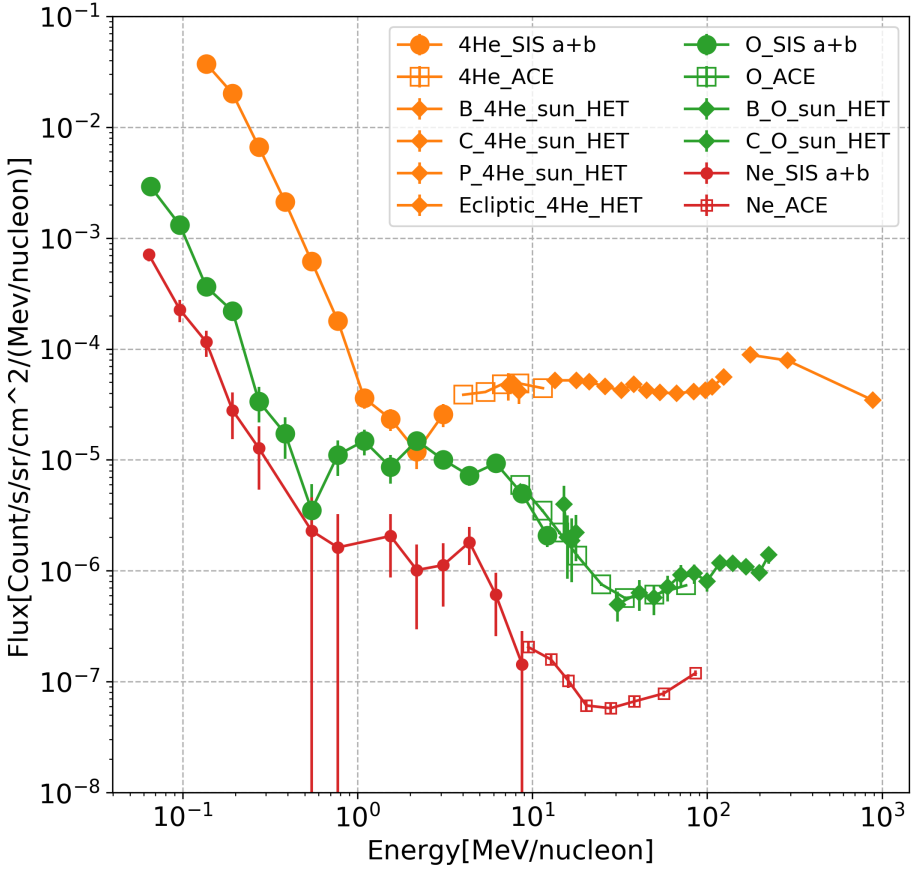




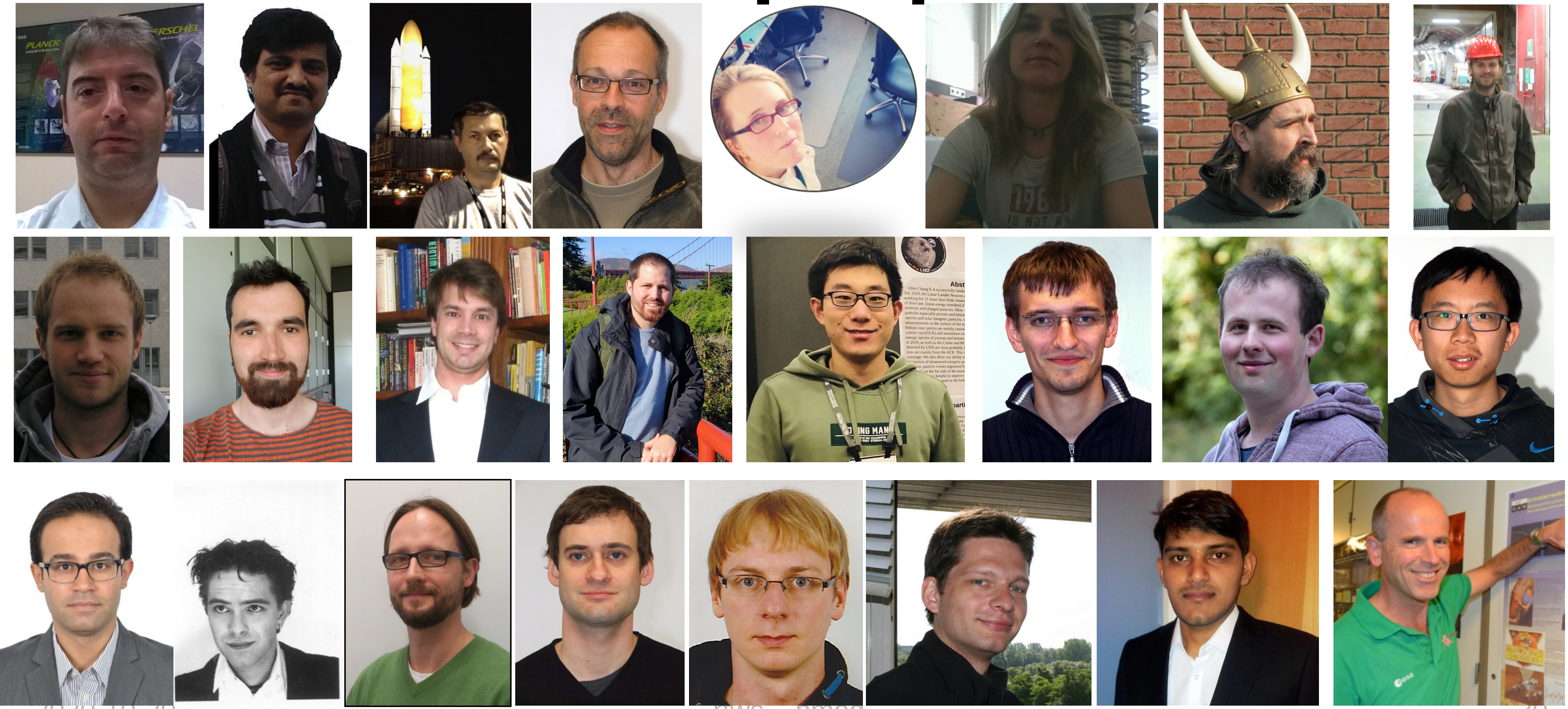
HET & SIS

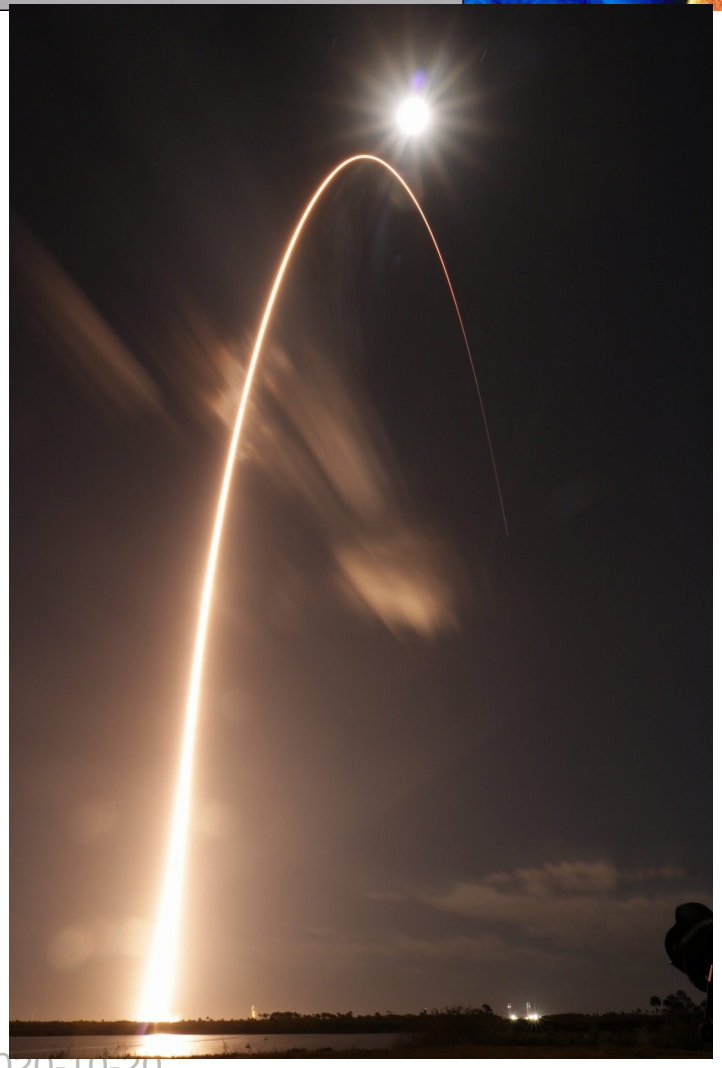
Combination of SIS&HET shows ACR





Kiel units and the people behind them






HEROES AND LEGENDS
UNITED STATES ASTRONAUT HALL OF FAME

Summary & Conclusions

- **EPD working very well**
- **Sun very quiet, very low background activity**
- **Isolated events:**
  - STEP sees lots of low-energy „activity“, difficult to interpret
  - Individual ion injections with velocity dispersion
  - Isolated electron injections
  - Only few particle events see so far
  - Forbush decrease to track CME propagation from 0.8 to 1 AU
  - ACR nicely seen
- 4 publications in preparation
- More to come as the Sun picks up in activity