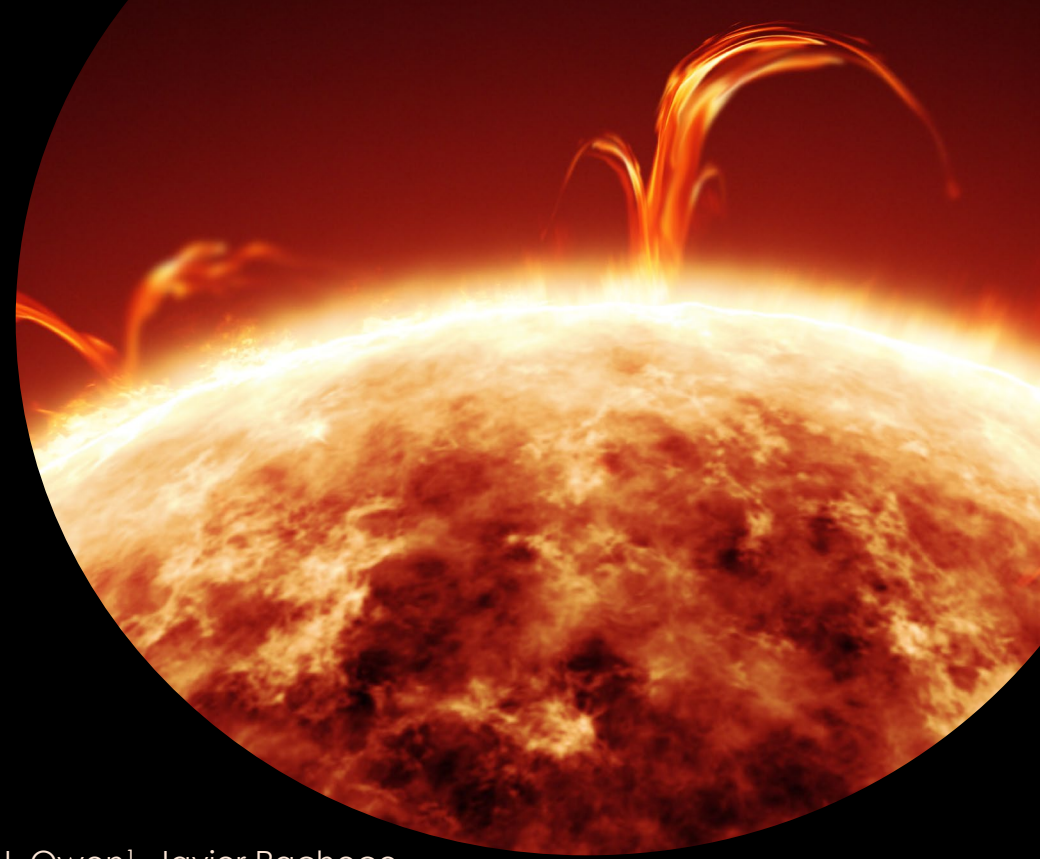


Solar Orbiter in-situ observations of electron beam – Langmuir wave interactions and how they modify electron spectra



Camille Y. Lorfing¹

Hamish A. S. Reid¹, Raul Gomez-Herrero², Milan Maksimovic³, Georgios Nicolaou¹, Christopher J. Owen¹, Javier Pacheco-Rodriguez², Domenico Trotta⁴, and Daniel Verscharen¹

¹*Mullard Space Science Laboratory, University College London*

²*Universidad de Alcala, Space Research Group, Spain*

³*LESIA, Observatoire de Paris, Universite PSL, CNRS, Sorbonne Universite, Univ. Paris Diderot, Sorbonne Paris Cite*

⁴*The Blackett Laboratory, Department of Physics, Imperial College London*

RPW team meeting - Prague, Czechia



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Langmuir waves co-temporal with electrons beams

Observations by spacecrafts like Helios and WIND

- poor temporal resolution
- measurements at fixed distance (0.3AU for Helios, 1AU for WIND)

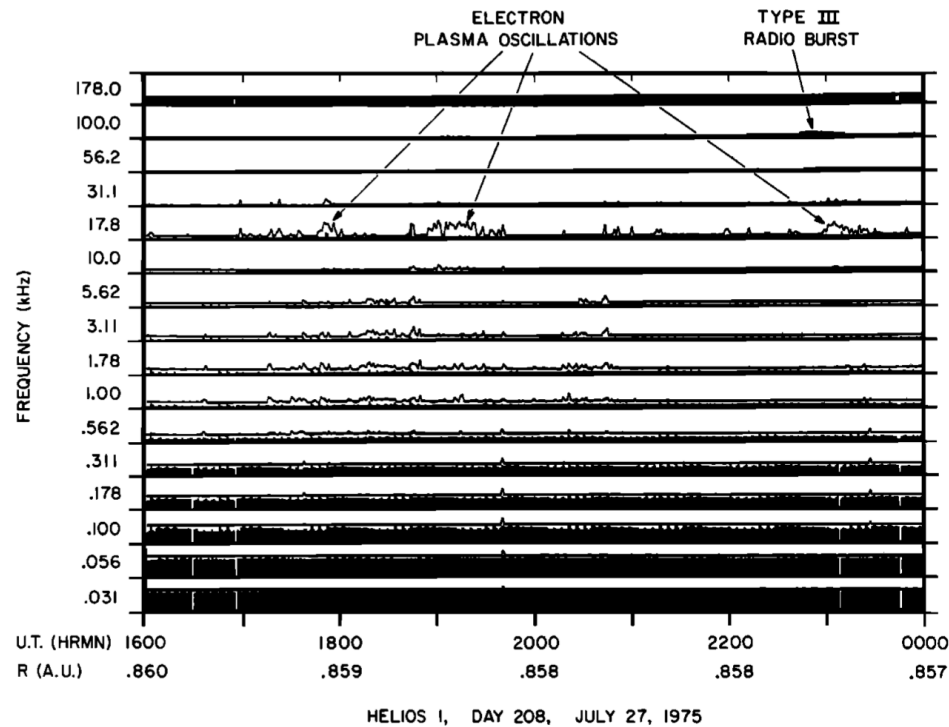


Fig. 14. Examples of electron plasma oscillations at $f \approx f_p^-$ detected during a period of enhanced solar flare activity.

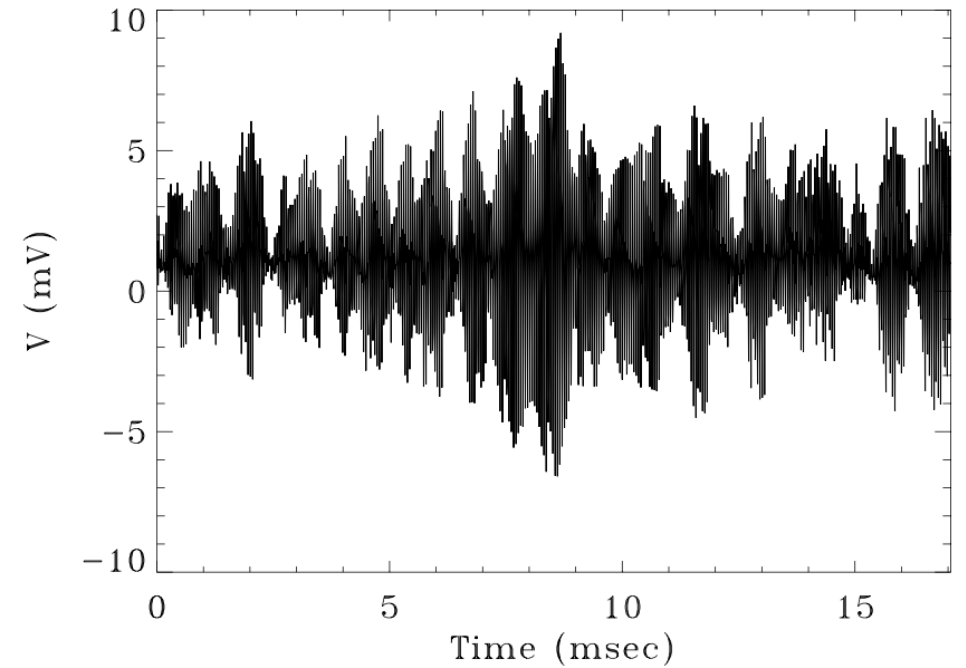


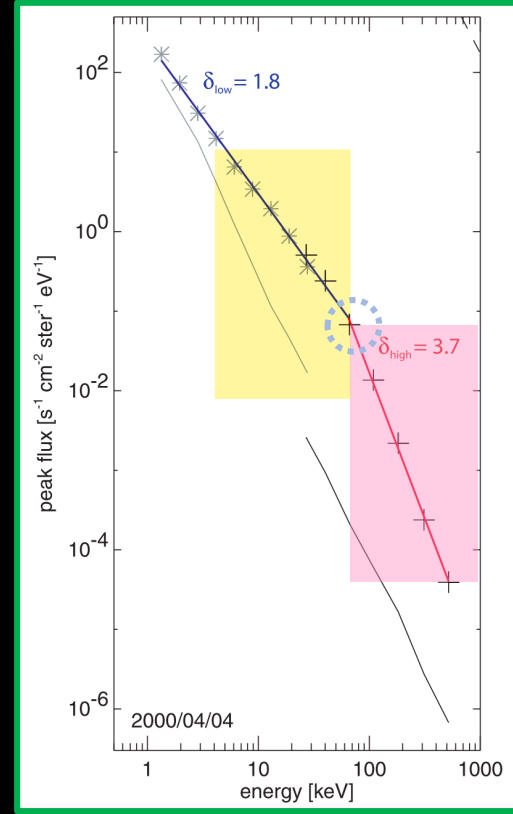
Fig. 5. Langmuir waveform as observed by WIND in the quiet solar wind (15/09/2007).

Briand, 2009

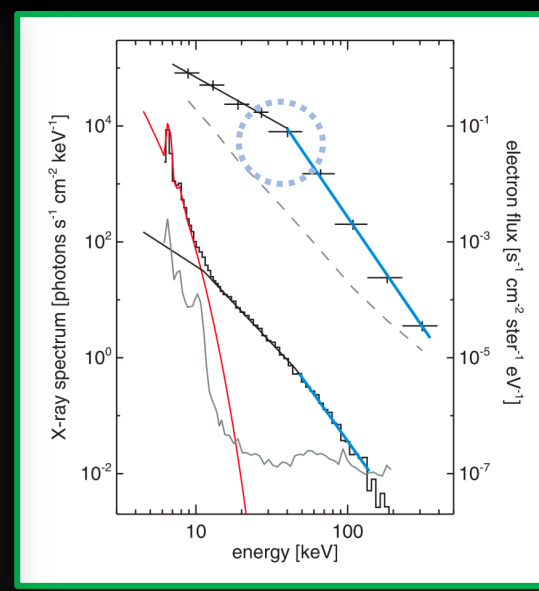
Broken power law

obs and sim work:

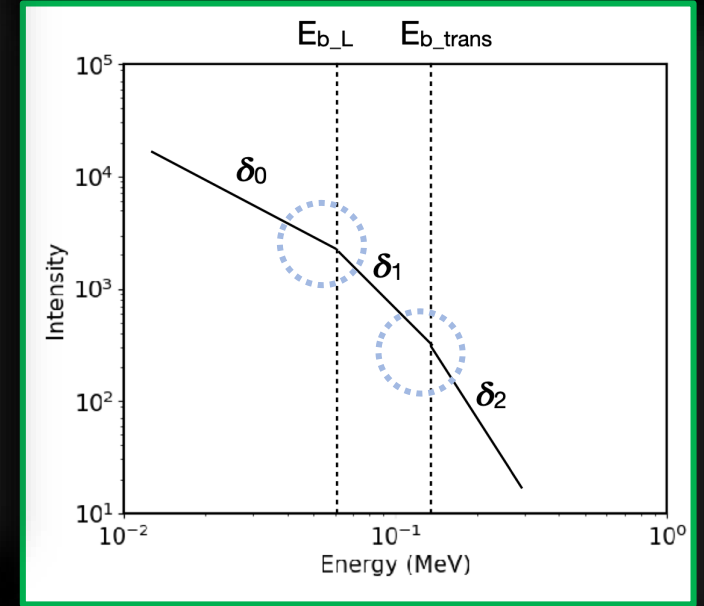
We observe a **broken power law** when fitting the peak electron flux vs energy



Krucker et al. 2009



Krucker et al. 2007

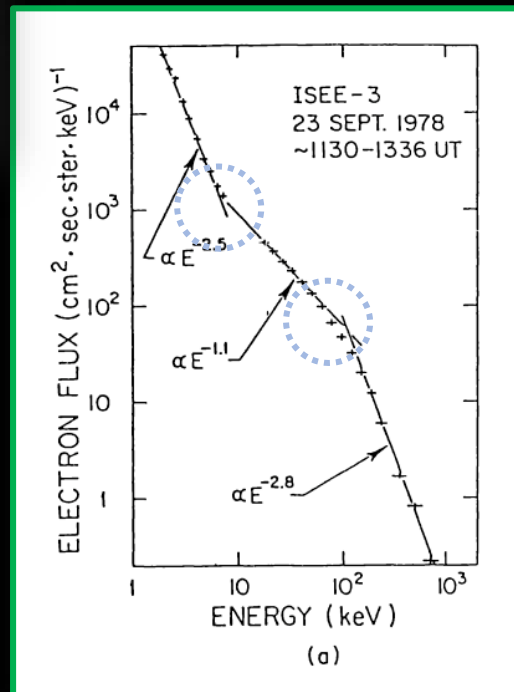


Dresing et al. 2021

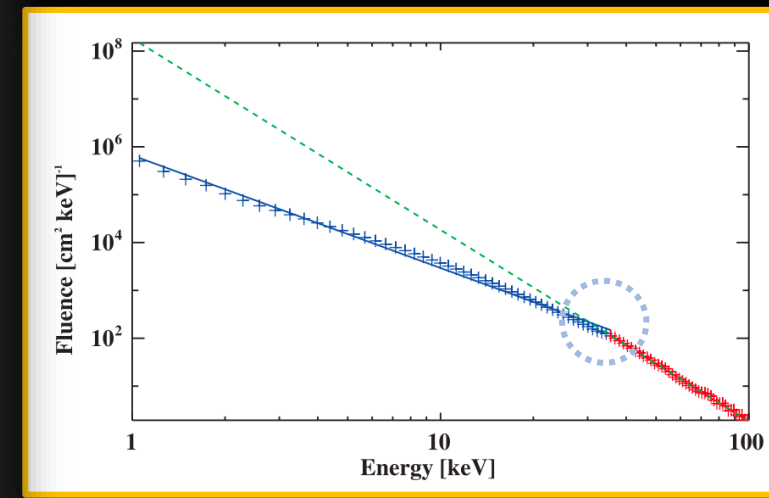
Solar Orbiter aims to understand the origin of multiple power-law features in solar electron spectra :

→ What causes this break?

→ At what energies does it happen?

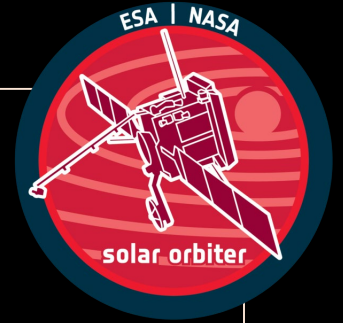


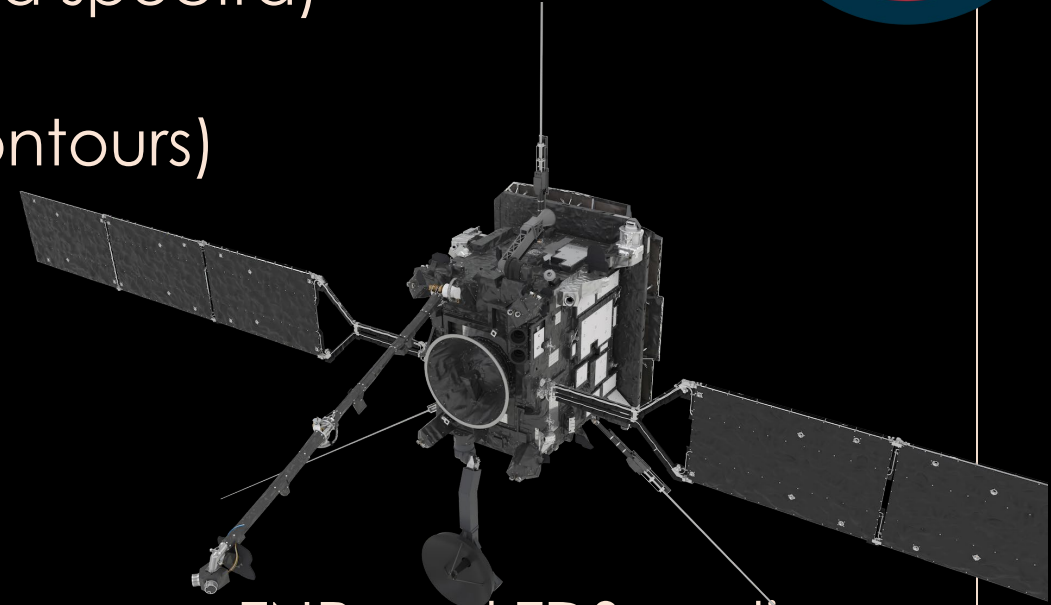
Lin et al. 1990



Kontar and Reid 2009

Solar Orbiter instruments in this study

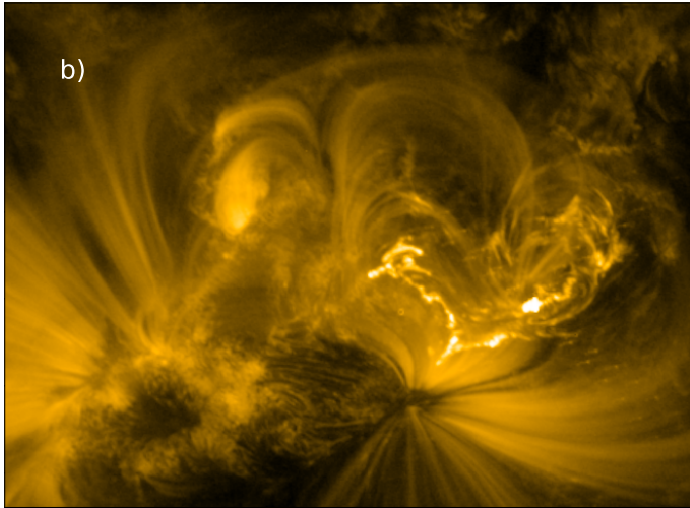


- **EPD** (electron distribution function and electron spectra)
 - **SWA** (electron distribution function and spectra)
 - **MAG** (magnetic field)
 - **STIX** (X-Ray light curves and image contours)
 - **EUI** (images of the sun in 174\AA)
- 
- A 3D rendering of the Solar Orbiter spacecraft, showing its complex structure, solar panels, and various instruments.
- **RPW** (plasma density - BIAS, Langmuir wave - TNR and TDS, radio dynamic spectrum - TNR)

*Multi-instrument study purpose: link electron measurements from **SWA** (eV range) to same measurements from **EPD** (few to hundred keV range)*

Electron flux, Langmuir waves, type III radio bursts at 0.68AU

Lorring et. al, 2023 (under review)

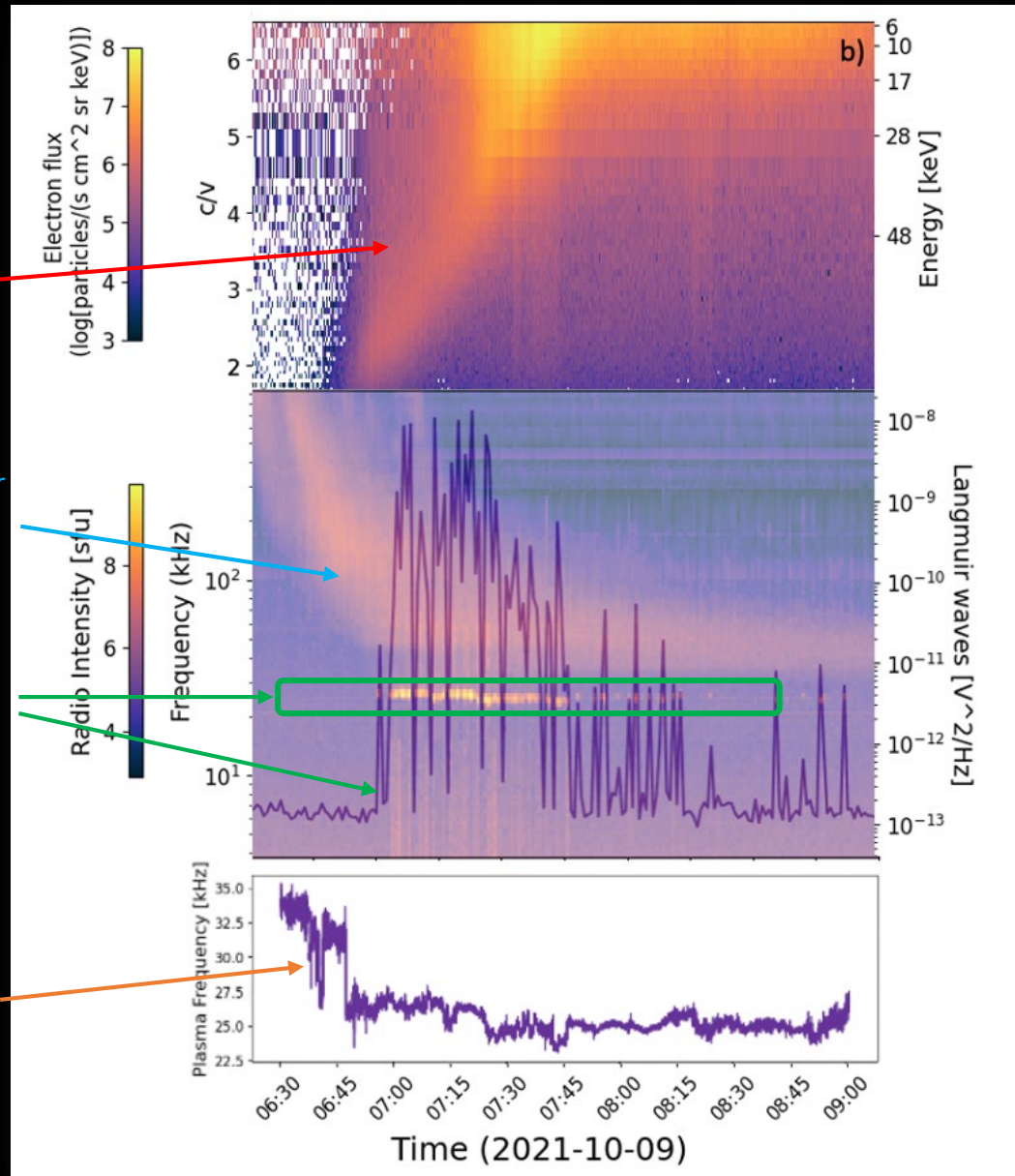


Electron beam

Type III solar radio burst

Langmuir waves

Plasma Frequency from electron density



Electron flux (STEP/EPD)

Radio dynamic spectrum (TNR/RPW)

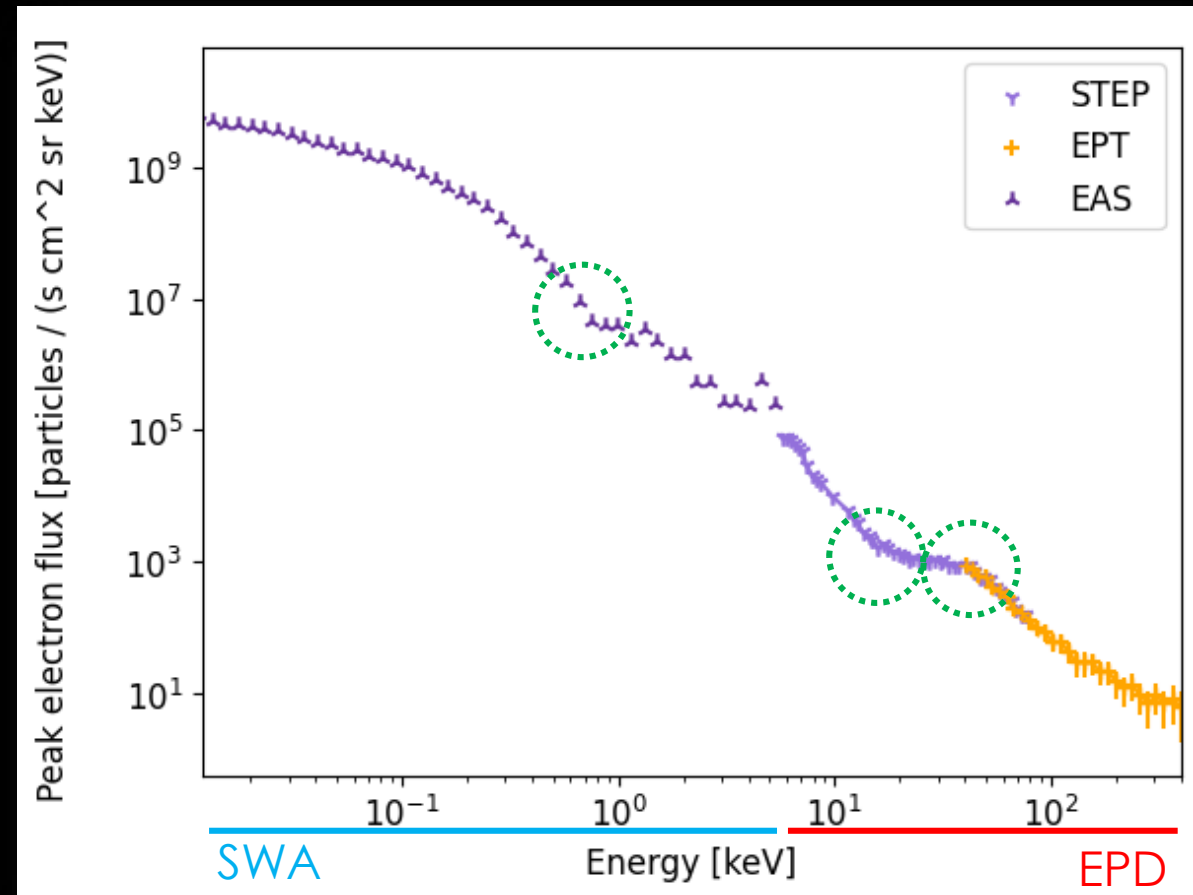
- EPD (STEP) observes electrons
- RPW (TNR, TDS, BIAS) observes associated type III radio bursts, Langmuir waves, and electron density
- LW co-temporal to the 60 keV electrons
- Spectral break in the electron spectrum around 50 keV

Electron spectrum

- What is the « *electron peak flux* » ?

It's the maximum of the electron flux per energy channel

- 1D array of the max flux value as a function of energy -> the electron spectrum
- Same analysis is performed on **EAS (SWA)** electrons and on **STEP-EPT (EPD)** electrons
- We see a lovely alignment between the electron spectra measured by both instruments!
- We observe **several breaks** in the electron spectrum (800 eV, 13keV, 40 keV)
 - why do these features appear?

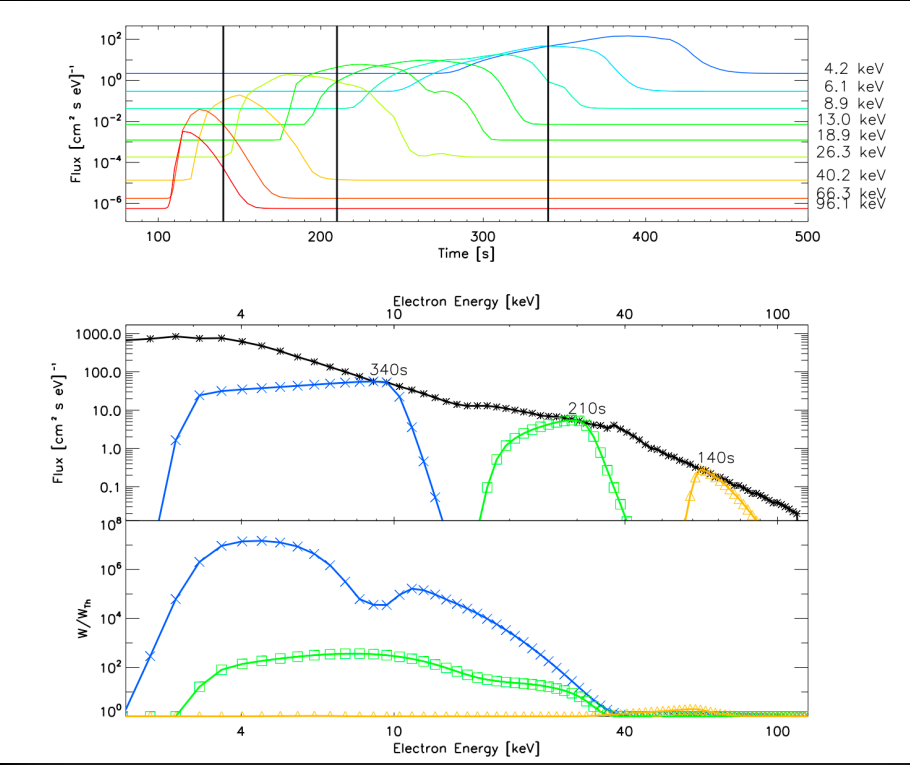


Lorring et. al, 2023 under review

Electron flux evolution

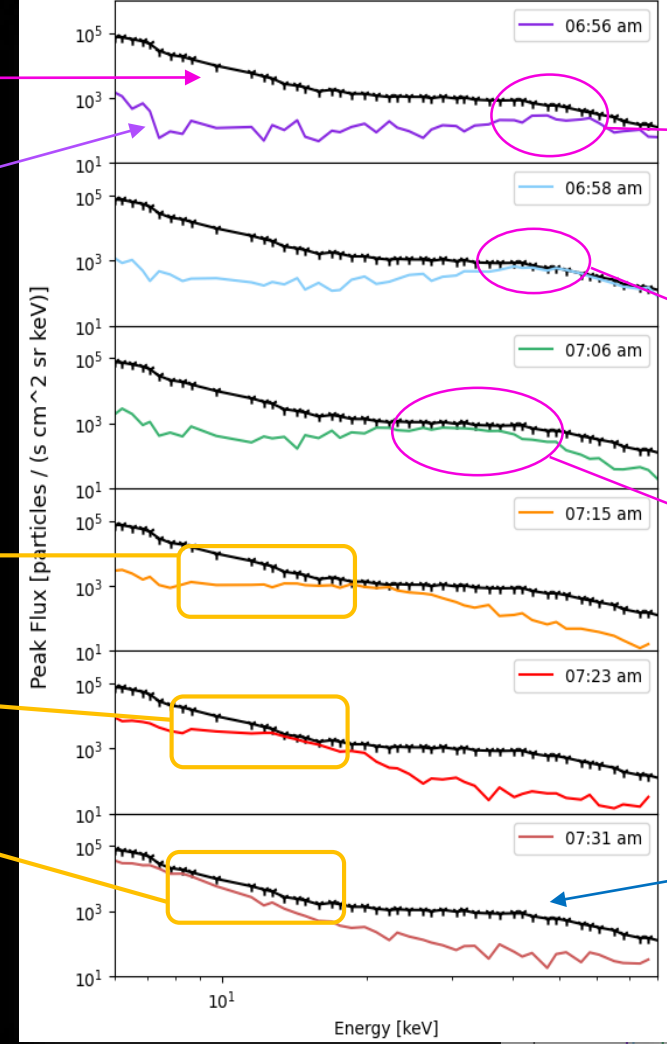
Lorring et. al, 2023 under review

→ What modifications of the electron flux cause the different features to appear on the electron spectrum?



Reid and Kontar 2013

Distribution flattens, appearance of a plateau at low energies
 $df/dv = 0$
 Distribution is aligned with the peak flux



flux at given timestamp

Electron spectrum

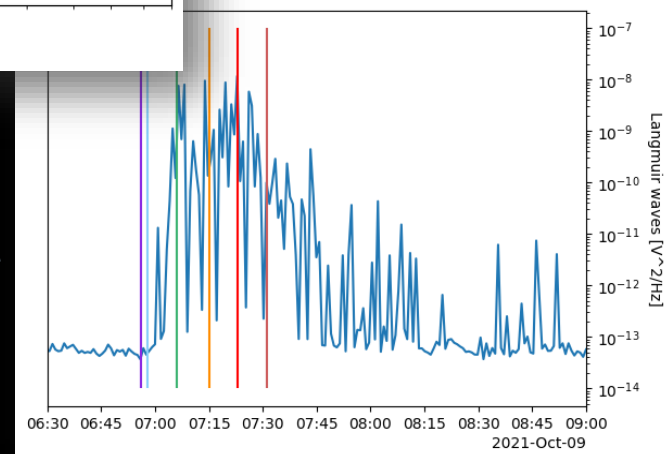
Bump in the flux, $df/dv > 0$

Bump moves down in velocity space as slower e- arrive to spacecraft

Distribution flattens and widens (Quasi Linear relaxation)

Inflexion point in spectrum caused by LW generation

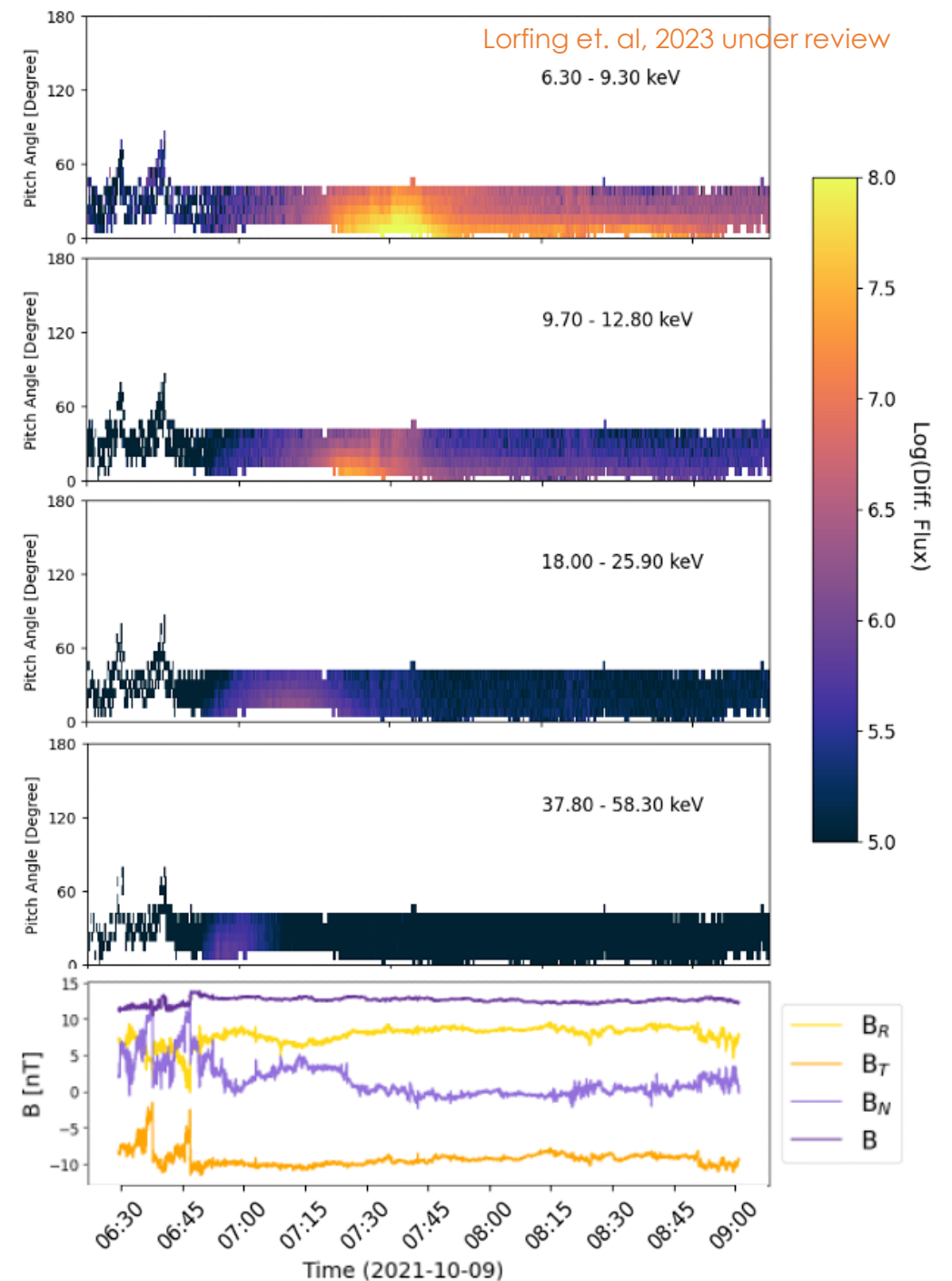
Langmuir waves grown above thermal level – vertical colour lines are the timestamps of the flux above



Pitch angle

→ *Could the spectral break be caused by pitch angle and not beam-plasma interactions?*

- Anisotropic beam
- If pitch angle scattering deflected the beam trajectory + was responsible for spectral break: expect to see it at around 50 keV on the PAD
- Pitch angle scattering doesn't affect non-thermal electrons
- Previous literature reports breaks due to pitch angle scattering at energies around 100-120 keV, way above any break we see in the spectrum
- Evidence to prove that the spectral breaks we observe are due to LW generation and wave-particle interactions, and not pitch angle scattering



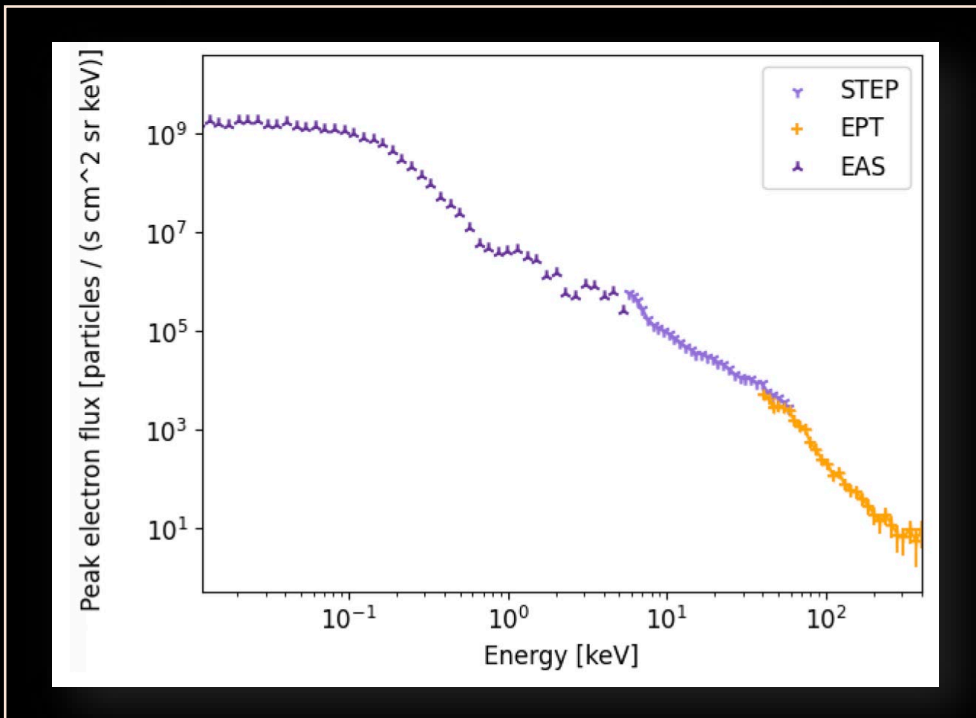
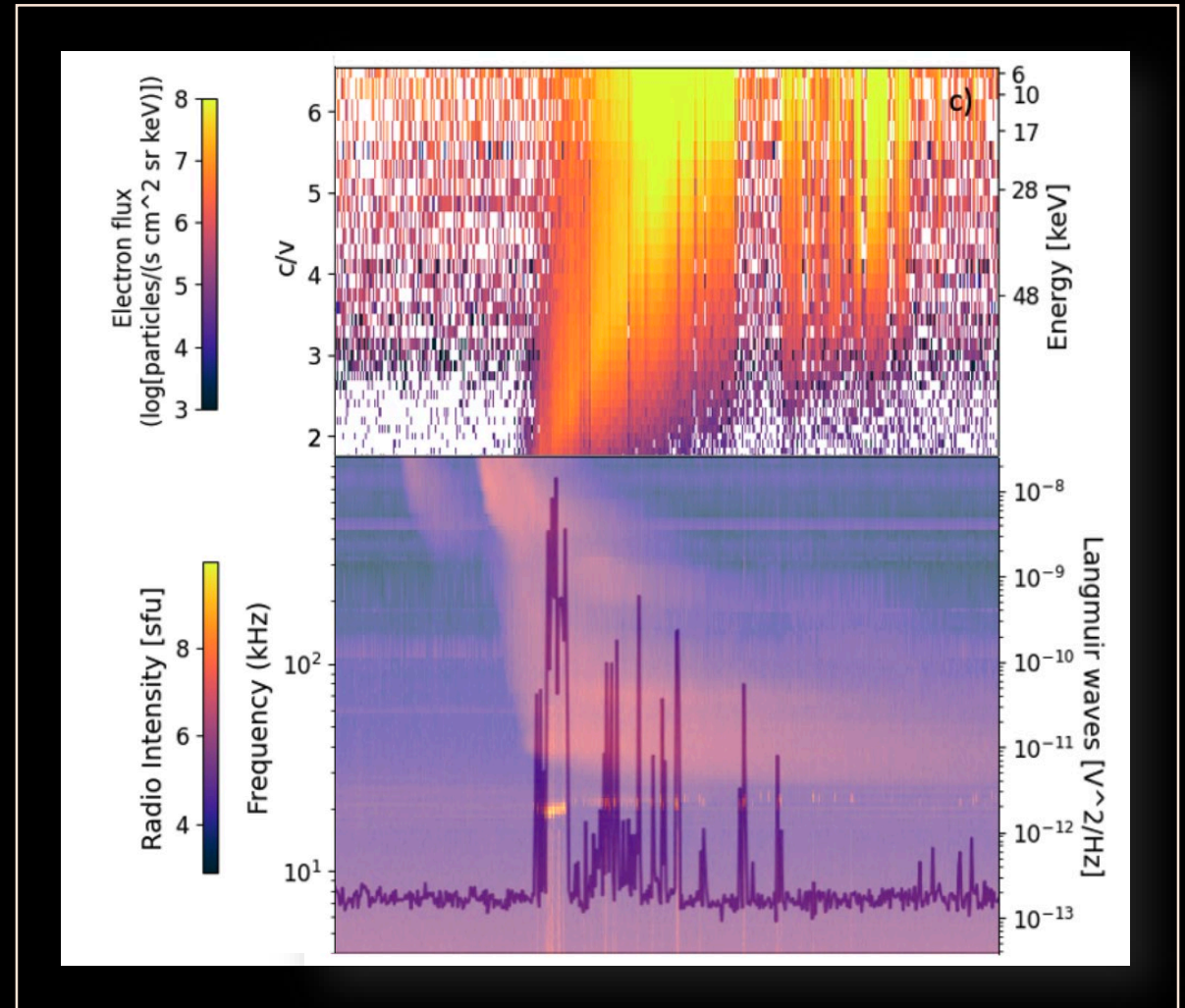
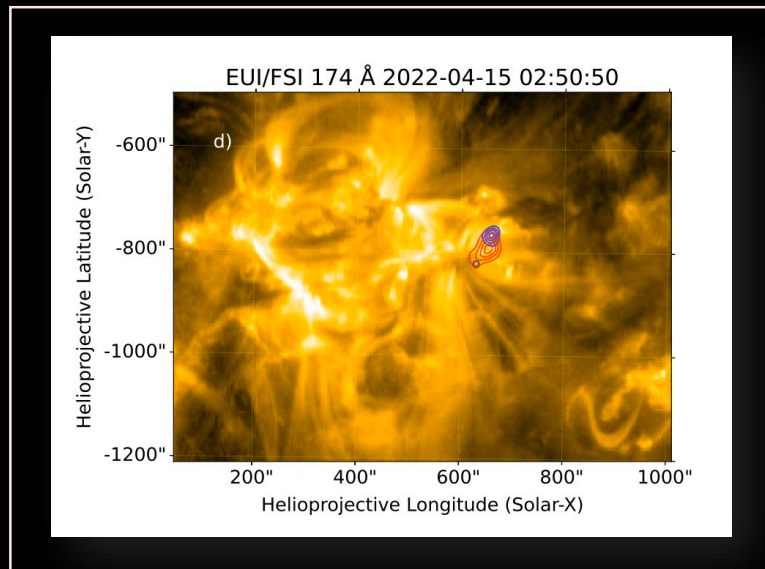
Key take-away points

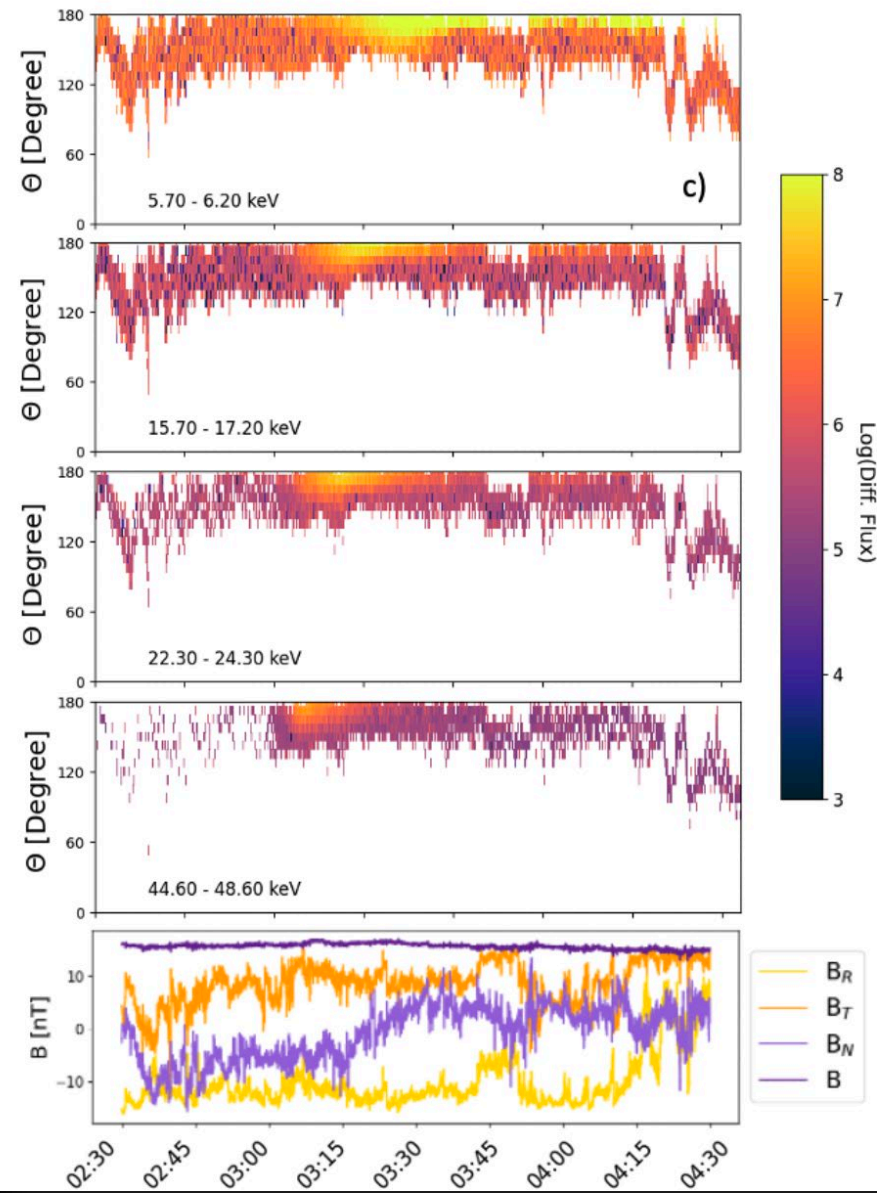
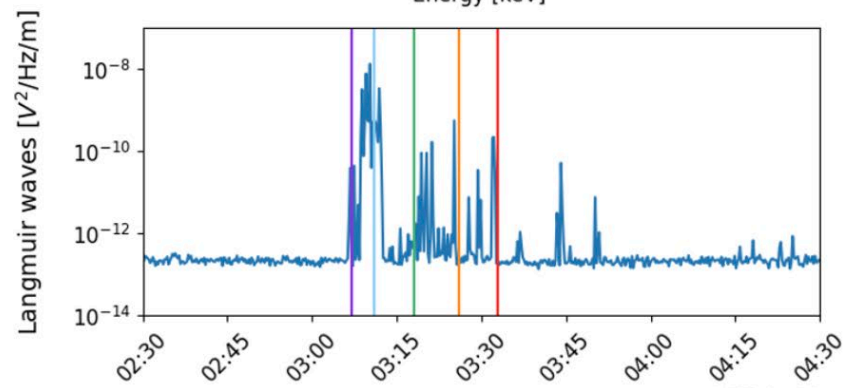
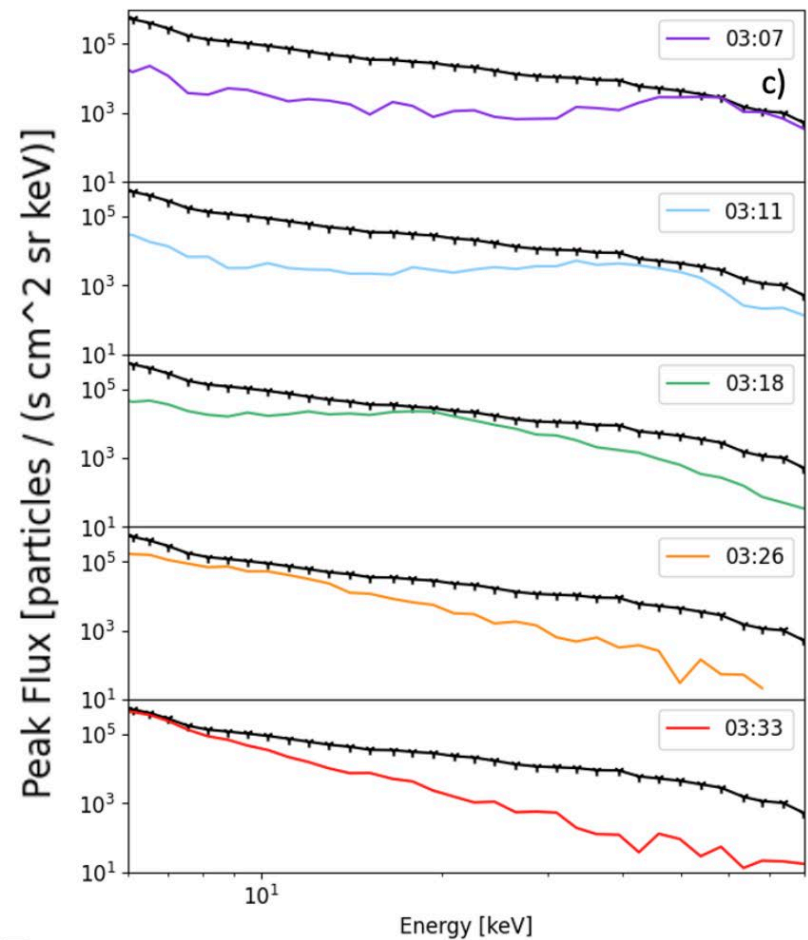
- Not all electron events have associated Langmuir waves observed
- Observe Langmuir waves with higher E closer to the Sun than typically observed at 1 AU
- **Break in electron spectrum in the deca-keV range is caused by wave-particle interactions**
- **First study that links electrons from all *Solar Orbiter* instruments and makes a bridge between EAS/SWA and STEP-EPT/EPD**

Watch out for Lorfing et al, 2023 in ApJ!



15th April 2022 – 0.5AU





24th November 2020 – 0.9AU

