How do wave-particle interactions in the heliosphere modify solar electron distribution functions?

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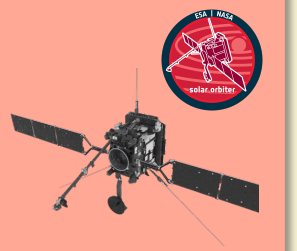
1. Electrons are emitted at the Sun

2. Electrons interact with background plasma:

growth of Langmuir waves

3. Langmuir waves interact with each other:

production of radio emission



4. Electrons detected in situ in solar wind by spacecrafts like *Solar Orbiter*

5. Track electron beams in the solar system via their radio emission

Langmuir waves co-temporal with electrons beams

Langmuir waves are observed co-temporal with electron beams by spacecrafts like Helios and WIND

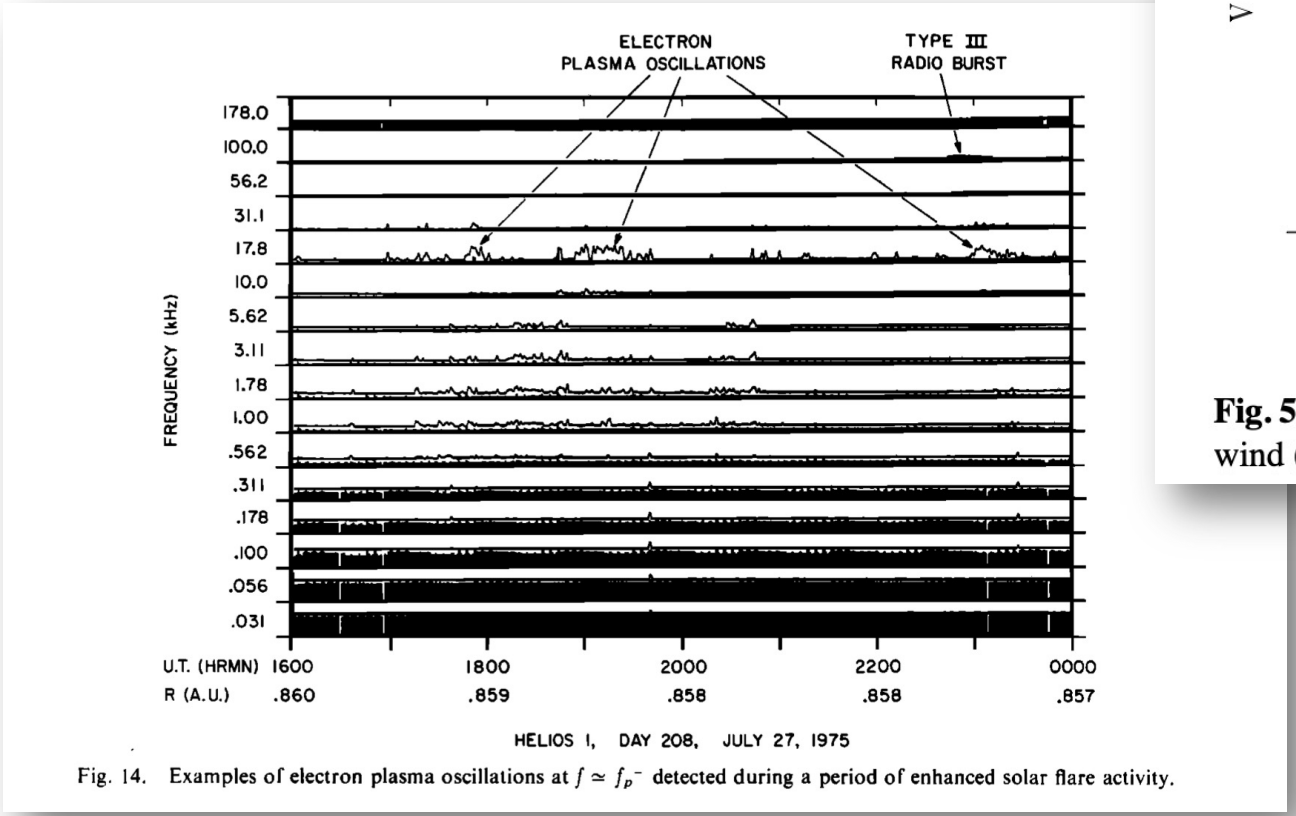


Fig. 14. Examples of electron plasma oscillations at $f \simeq f_p^-$ detected during a period of enhanced solar flare activity.

Gurnett and Anderson, 1977

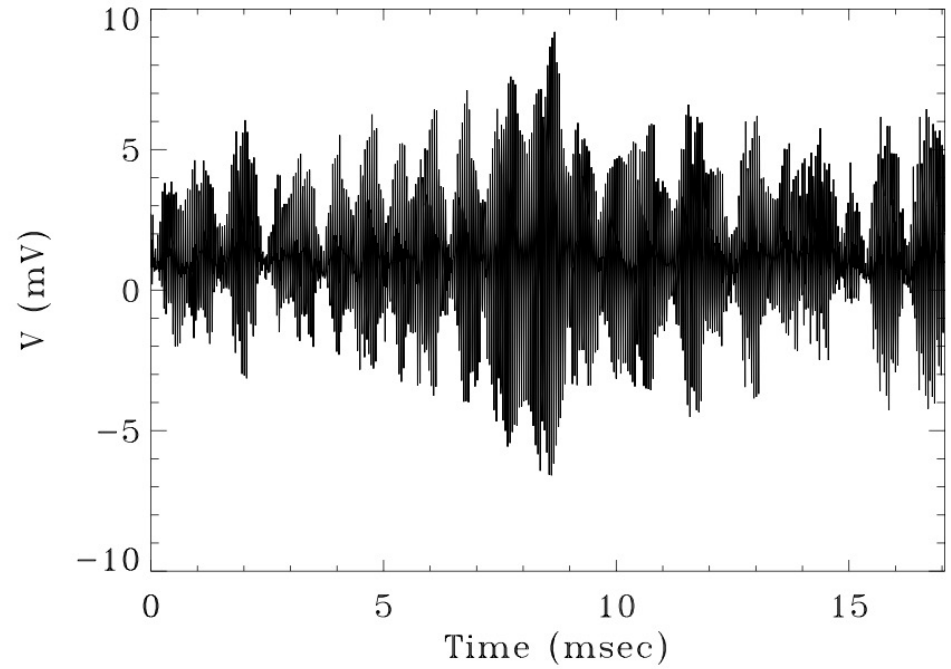


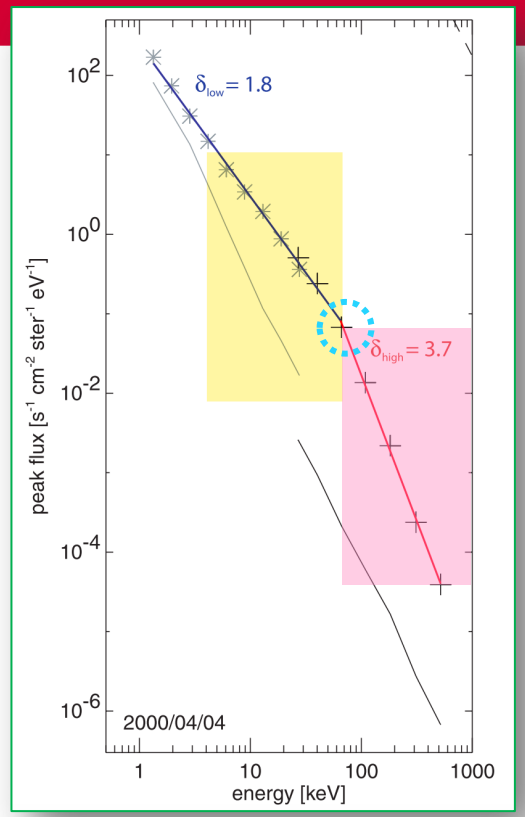
Fig. 5. Langmuir waveform as observed by WIND in the quiet solar wind (15/09/2007).

Briand, 2009

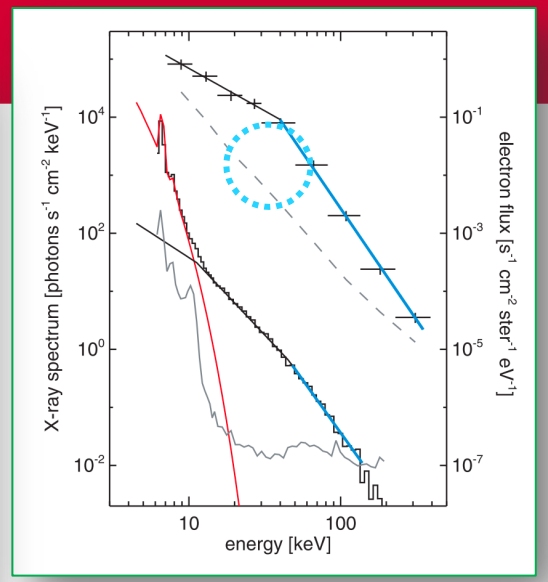
Broken power law

obs and sim work:

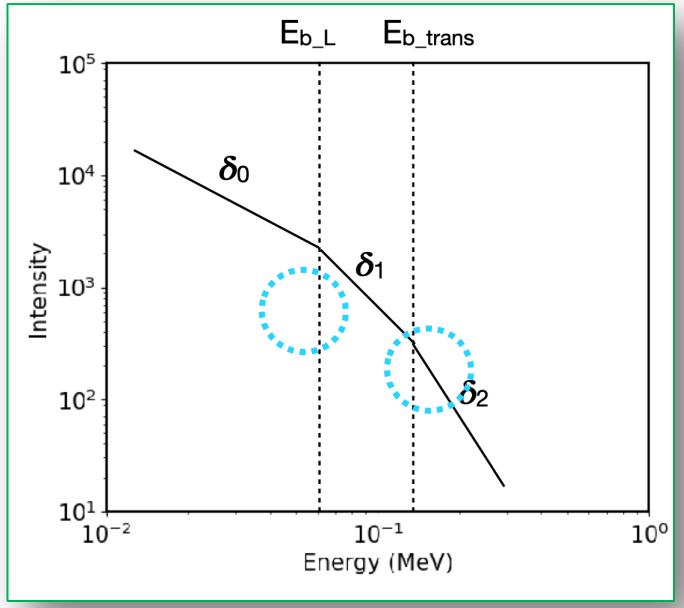
broken power law when fitting the peak electron flux vs energy



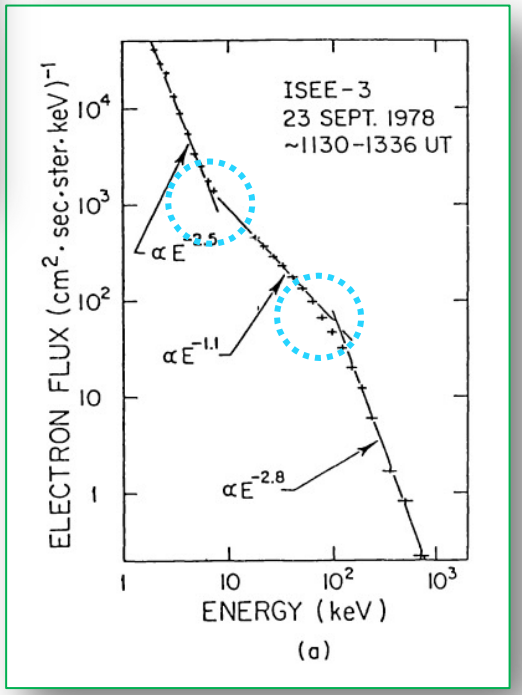
Krucker et al. 2009



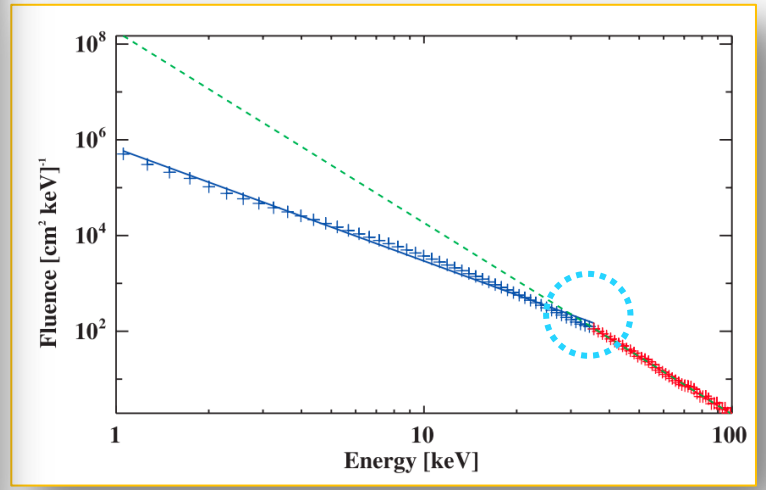
Krucker et al. 2007



Dresing et al. 2021



Lin et al. 1990



Kontar and Reid 2009

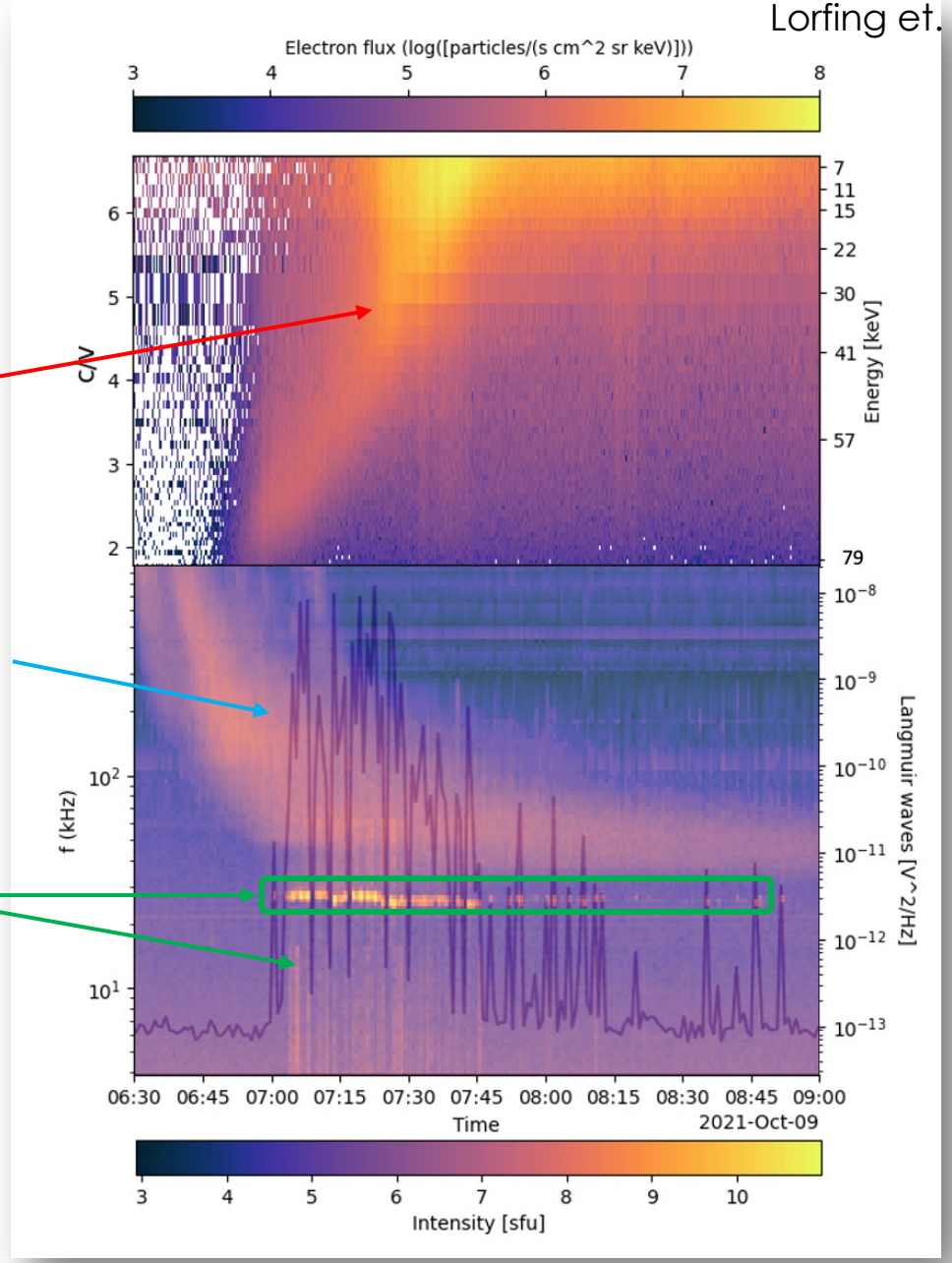
→ What causes this break?

→ At what energies does it happen?

Electron flux, Langmuir waves, type III radio bursts

- EPD (STEP/EPT) observes electrons
- RPW (TNR) observes associated type III radio bursts
- Solar Orbiter is in the right position to measure the locally generated Langmuir waves
- We observe LW co-temporal to the 60 keV electrons
- 50 keV is around the energy of the spectral break observed in the electron spectrum

Lorfing et. al, 2023 in prep



Electron beam

Type III solar radio burst

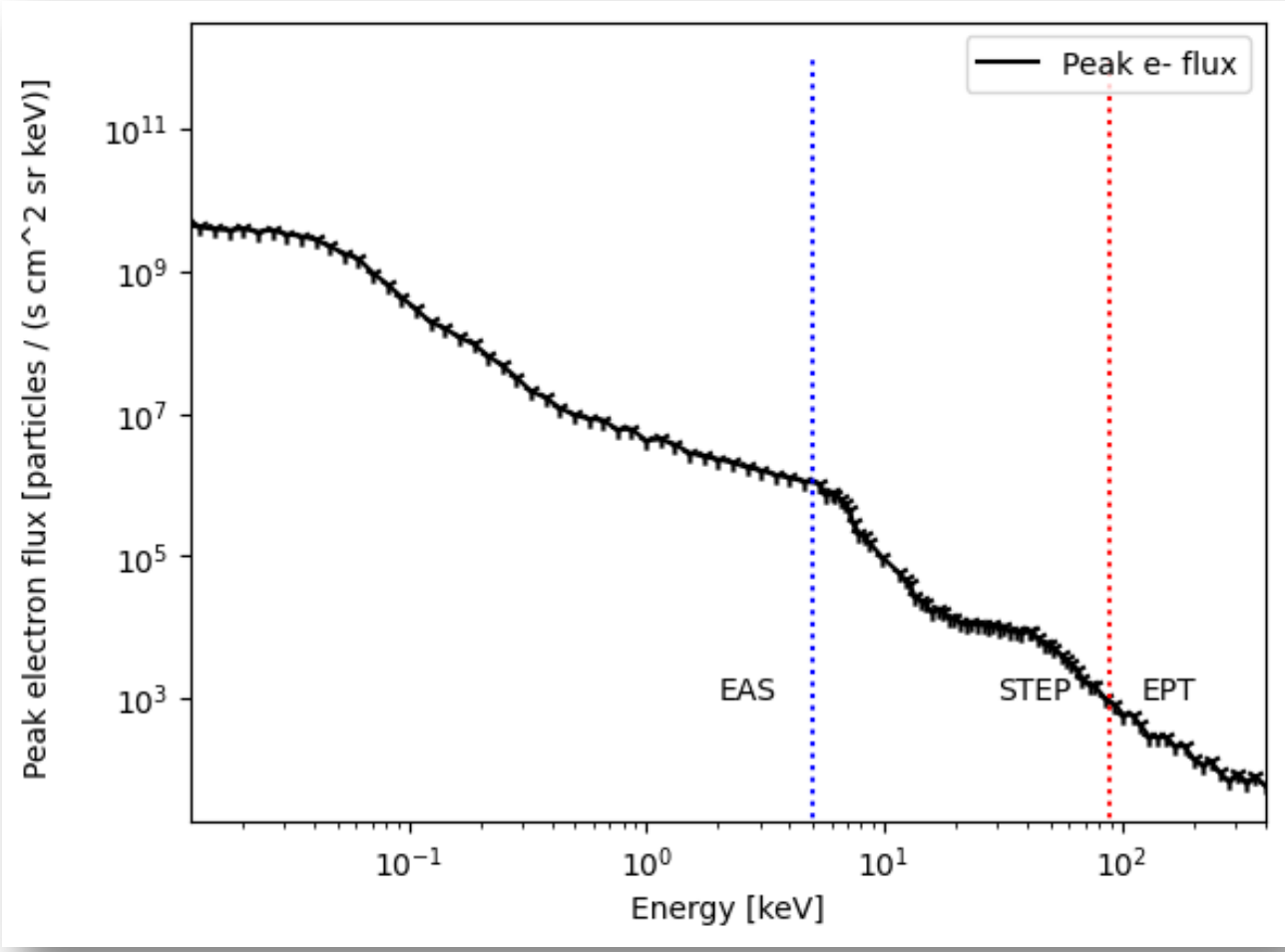
Langmuir waves

Electron flux (STEP/EPD)

Radio dynamic spectrum (TNR/RPW)

Electron spectrum

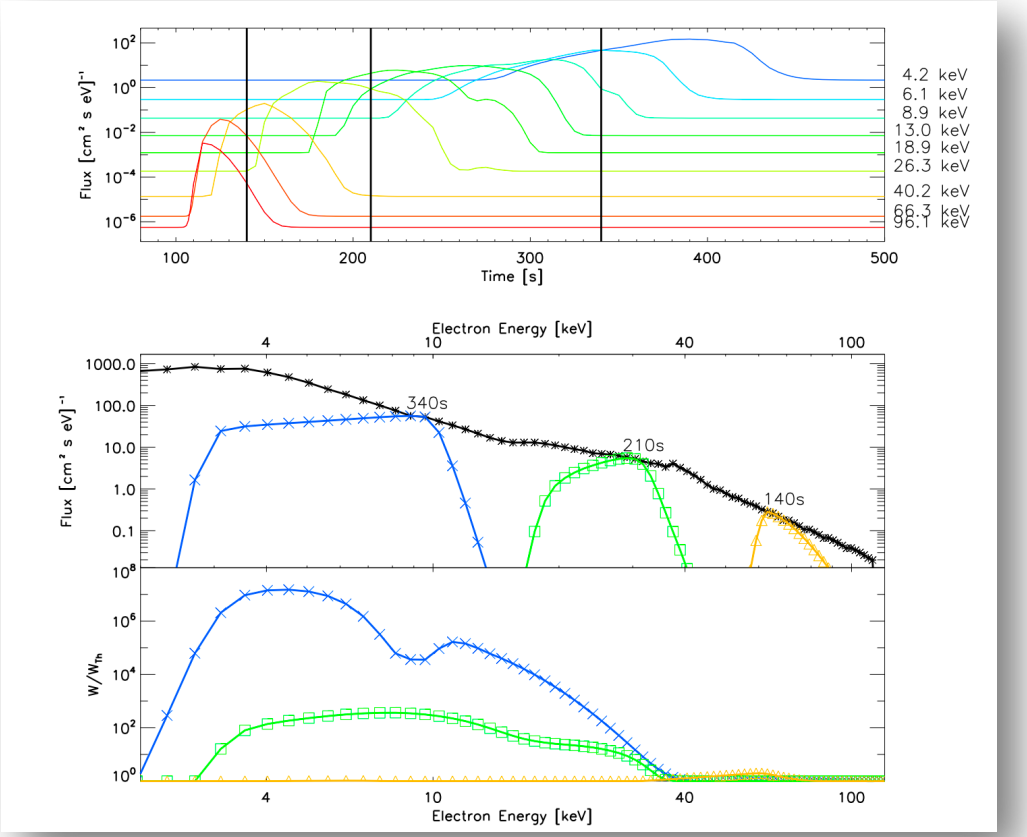
- What is the « electron peak flux » ?
- Maximum of the electron flux per energy channel
- Result:1D array of the max flux value as a function of energy -> the electron spectrum
- The same analysis is performed on EAS (SWA) electrons, and on STEP-EPT (EPD) electrons
- We see a lovely alignment between the electron spectram measured by both instruments!
- We observe several breaks in the electron spectrum -> why do these features appear?



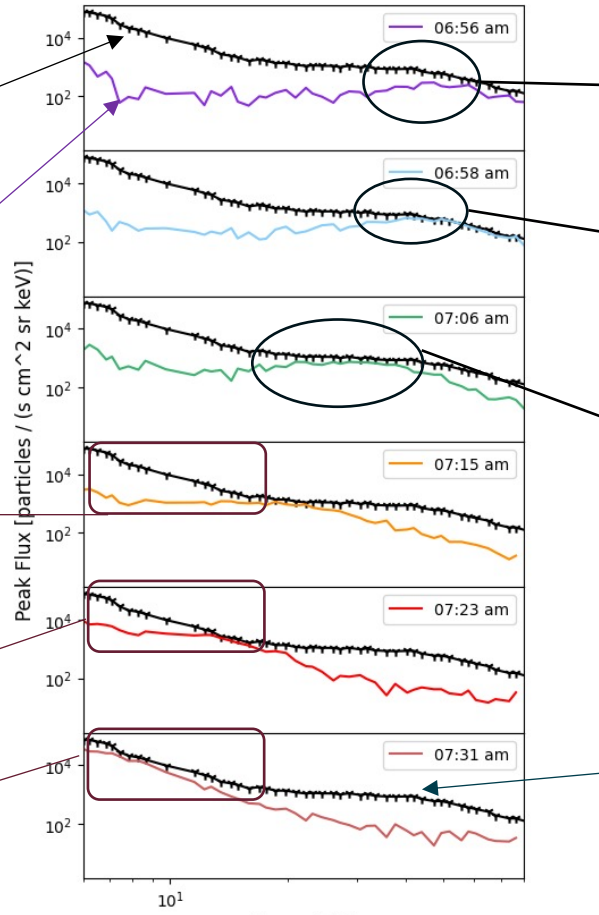
Lorfing et. al, 2023 in prep

Electron flux evolution

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



Reid and Kontar 2013



Electron spectrum

flux at given timestamp

Bump in the flux, df/fv > 0

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

Distribution flattens and widens (Quasi Linear relaxation)

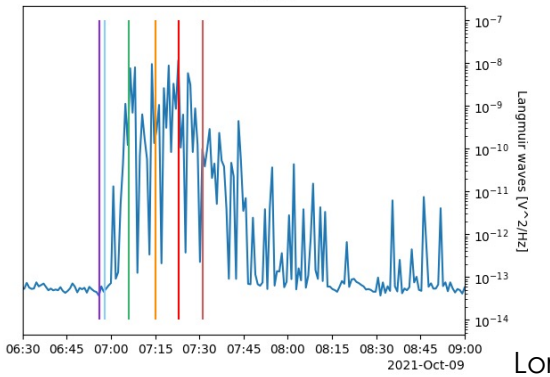
Distribution flattens, appearance of a plateau at low energies

df/dv = 0

Distribution is aligned with the peak flux

Inflexion point in spectrum caused by LW generation

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

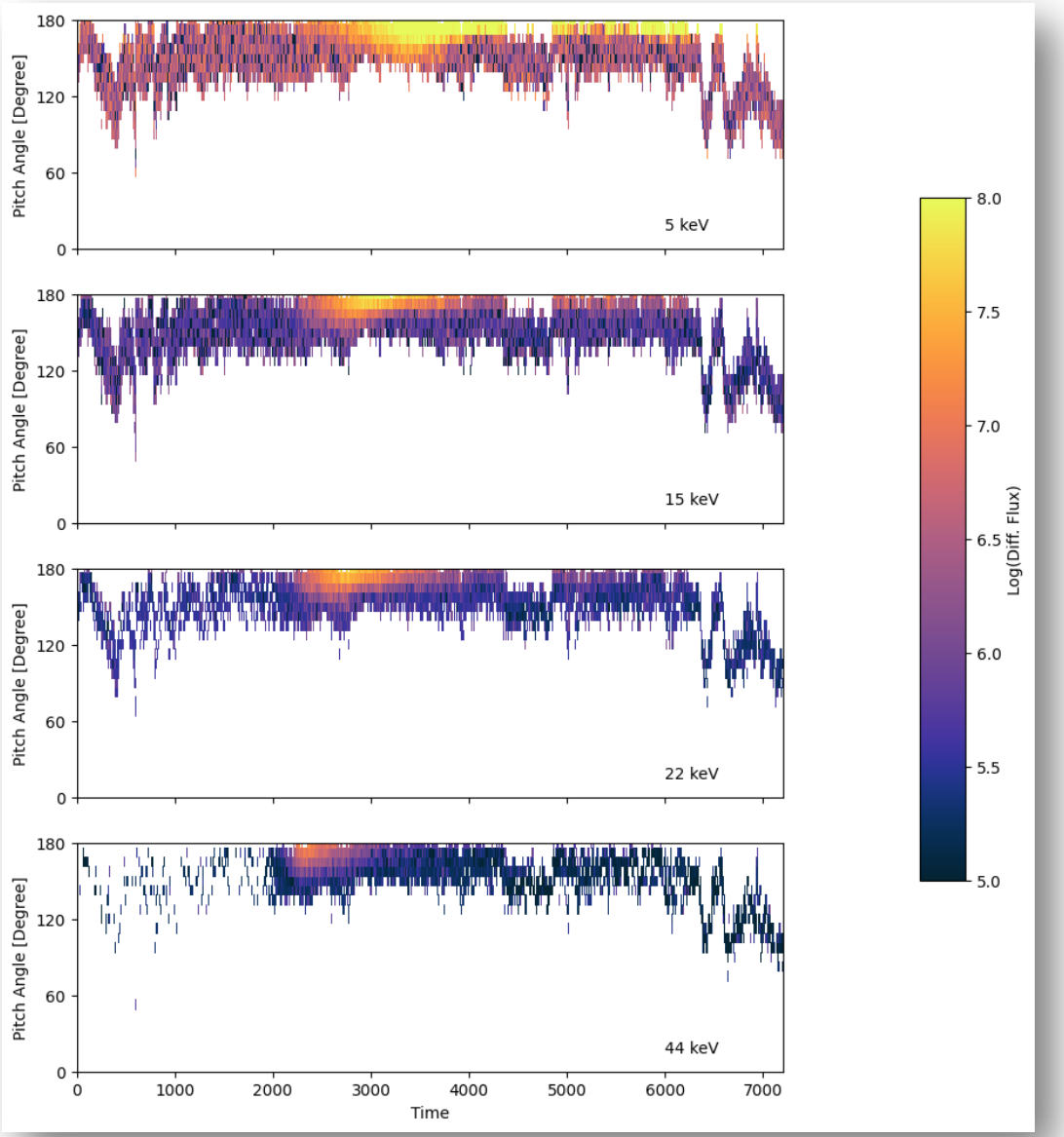


Lorfing et. al, 2023 in prep

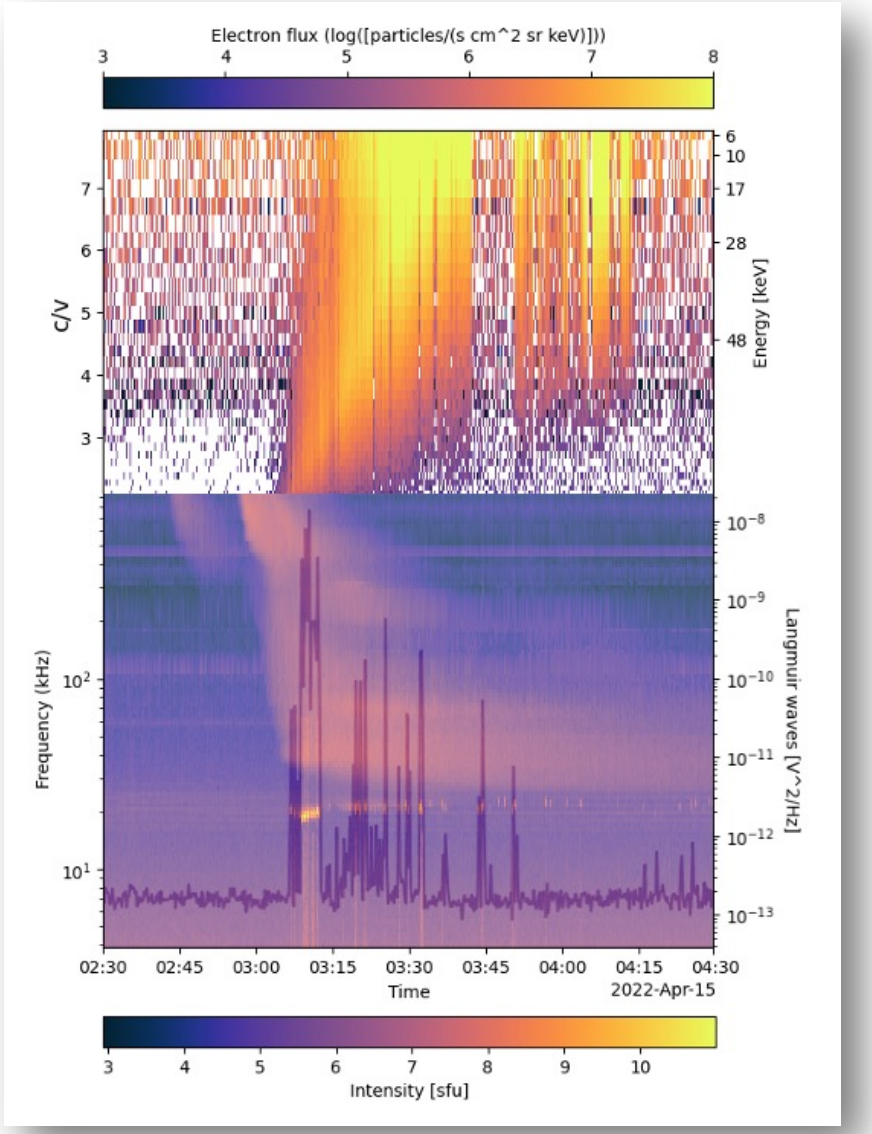
Pitch angle

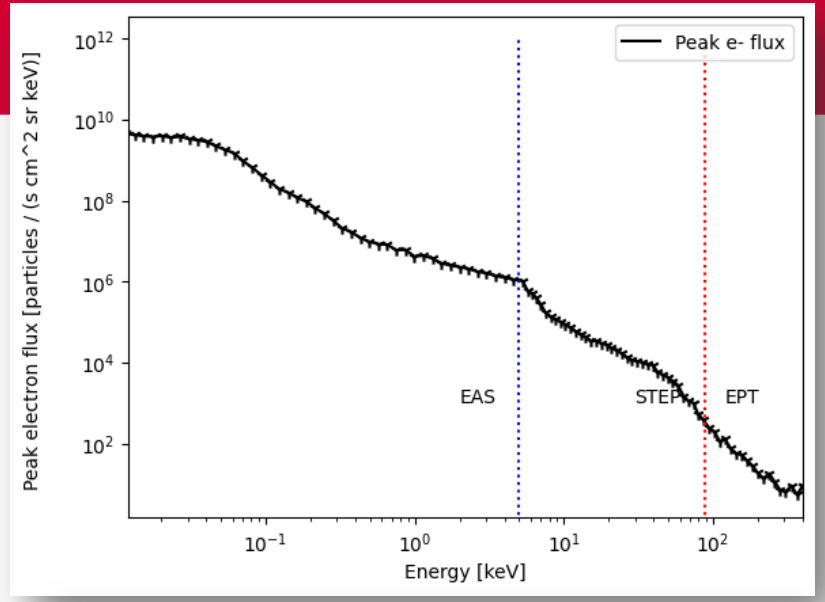
Could the spectral break be caused by pitch angle and not beam-plasma interactions?

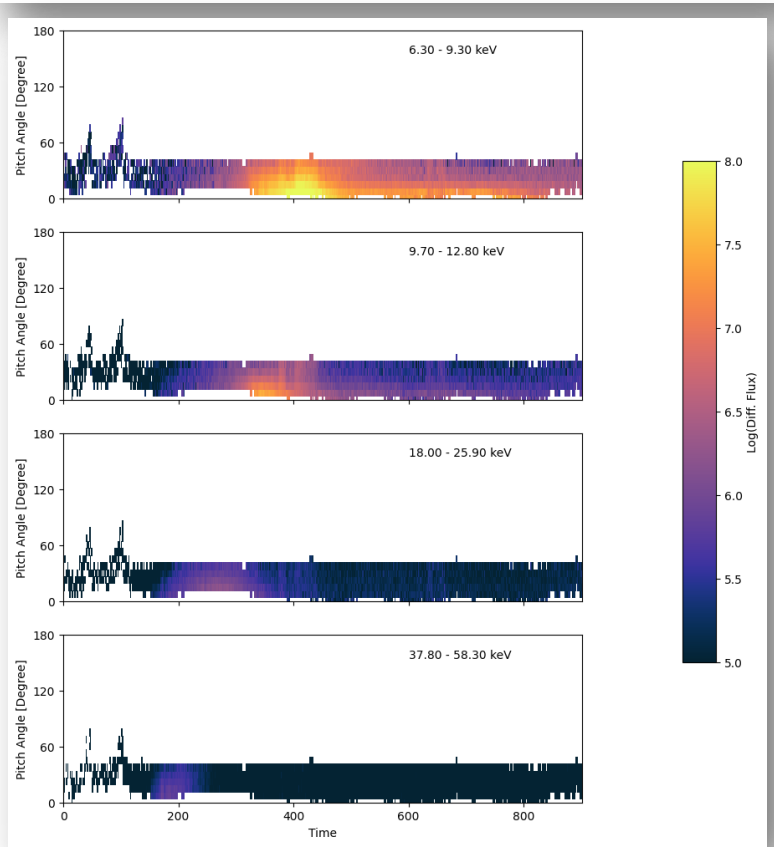
- Anisotropic beam
- If pitch angle scattering deflected the beam trajectory + was responsible for spectral break: expect to see it at around 50 keV on the PAD
- Pitch angle is dependent on energy -> scattering doesnt affect non-thermal electrons
- Previous literature reports breaks due to pitch angle 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.

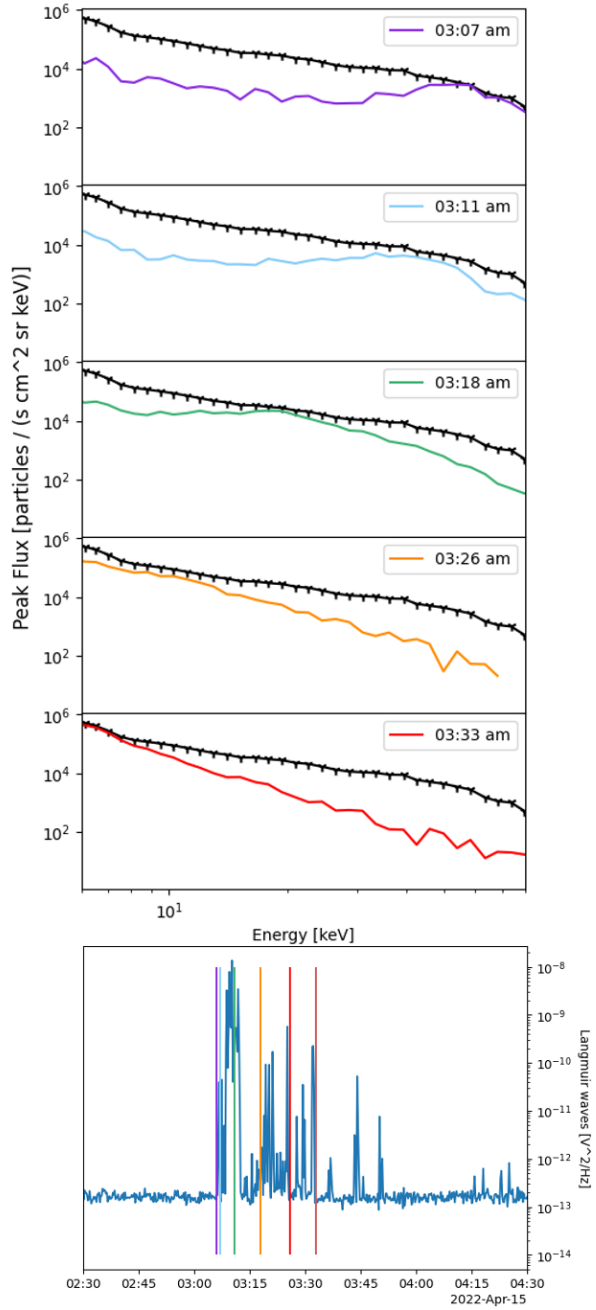


15/4/2022 event









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 1AU
- Break in electron spectrum in the deca-keV range is caused by wave-particle interactions
- Break at 5keV seems suspicious as occurs at meeting of both instruments
- Evidence of quasi-linear relaxation in the evolution of the electron flux due to interactions
- Pitch angle not the cause of the break at these energies
- First study that links electrons from all Solar Orbiter instruments and makes a bridge between EAS/SWA and STEP-EPT/EPD

To be submitted soon, watch out for Lorfing et al 2023!