Solar energetic electrons and Langmuir waves: a match made in the heliosphere

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Motivation: *How does the energy density of solar electron beams vary at different distances from the Sun?*

- **What I did:** Beam-plasma interactions using Quasilinear theory + kinetic Fokker-Planck approach

→ Which electron energies interact with Langmuir waves as a function of distance from the Sun?

Wave-particle interactions
Expansion + propagation of the beam in space
Particle collisions
Source function
Group velocity of LW
Refraction of LW
Landau damping
Wave collisions
Spontaneous emission

$$\frac{\partial f}{\partial t} + \frac{v}{M(r)}\frac{\partial}{\partial r}M(r)f = \frac{4\pi^2 e^2}{m_e^2}\frac{\partial}{\partial v}\left(\frac{W}{v}\frac{\partial f}{\partial v}\right) + \frac{4\pi n_e e^4}{m_e^2}\ln\Lambda\frac{\partial}{\partial v}\frac{f}{v^2} + S(v,r,t) \quad (1)$$

$$\frac{\partial W}{\partial t} + \frac{\partial \omega_L}{\partial k}\frac{\partial W}{\partial r} - \frac{\partial \omega_{pe}}{\partial r}\frac{\partial W}{\partial k} = \frac{\pi\omega_{pe}}{n_e}v^2 W\frac{\partial f}{\partial v} - (\gamma_L + \gamma_c)W + e^2\omega_{pe}vf\ln\frac{v}{v_{Te}}, \quad (2)$$

Reid and Kontar 2013

Initial Conditions:

$$S(v,r,t=0) = A_v v^{-\alpha} exp\left(-\frac{r^2}{d^2}\right)$$

Electron distribution function:

$n_{beam} = 10^7$ cm^{-3} alpha = 8
$v_{min} = 10^9$ cm/s $v_{max} = 2\times10^{10}$ cm/s
$v_{beam} = 2\times10^9$ cm/s

Background Plasma:

$T_e = T_i = 10^6$K
No turbulence

- **What I want to do:** Statistical analysis of several impulsive electron events with energies up to few 100s keV

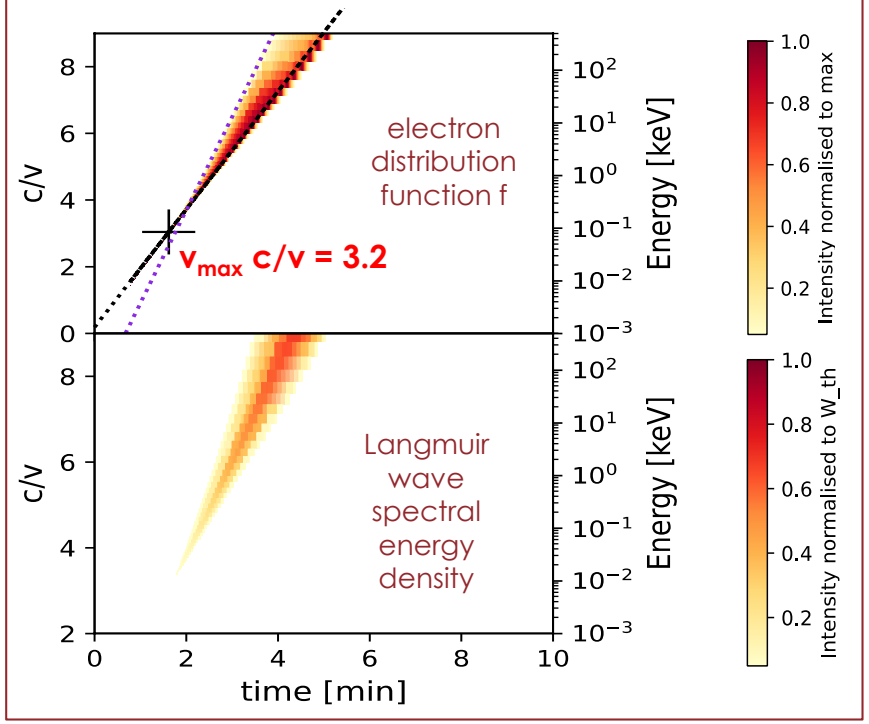
EPD (electron distribution function + arrival time)
SWA (electron temp/density/velocity)
RPW (electromagnetic field) data

- Instrumentation effects
  - ➢ scattering in sensor/different parts of detector
  - ➢ delay in electron arrival perceived at instrument

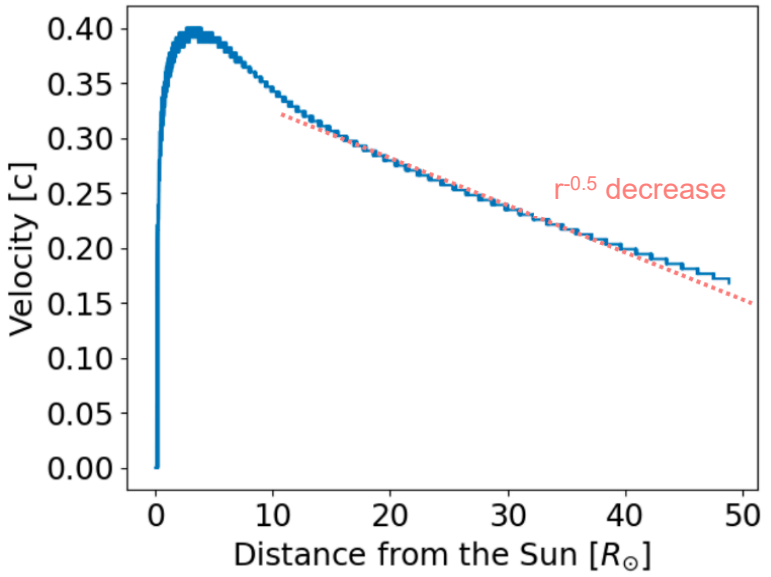
- Electron events measured simultaneously by all the SolO in-situ instruments

Main results from project/paper 1

1. electron distribution function and Langmuir wave growth *(15 solar radii = 0.06AU)*



2. Maximum electron velocity growing Langmuir waves

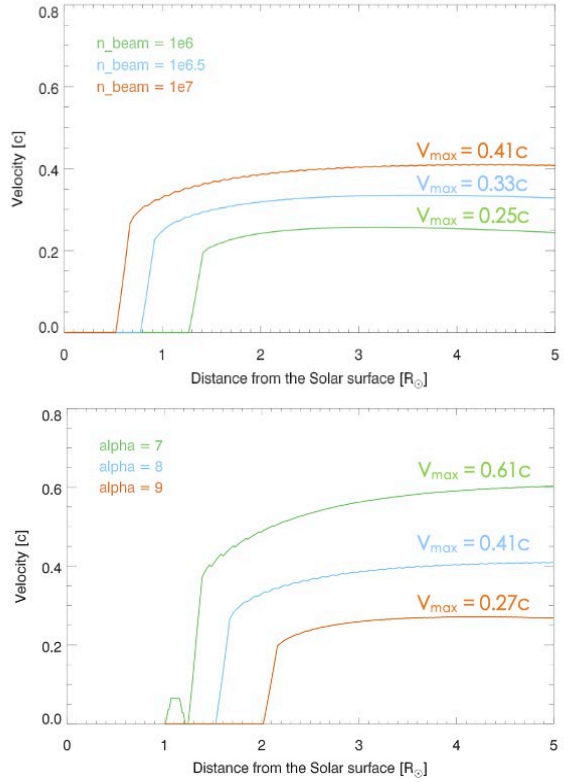


3. Varying the n_{beam} and alpha

Initial energy beam density: $U(t=0) \propto n_{beam} v^{-\alpha}$

beam density = n_beam

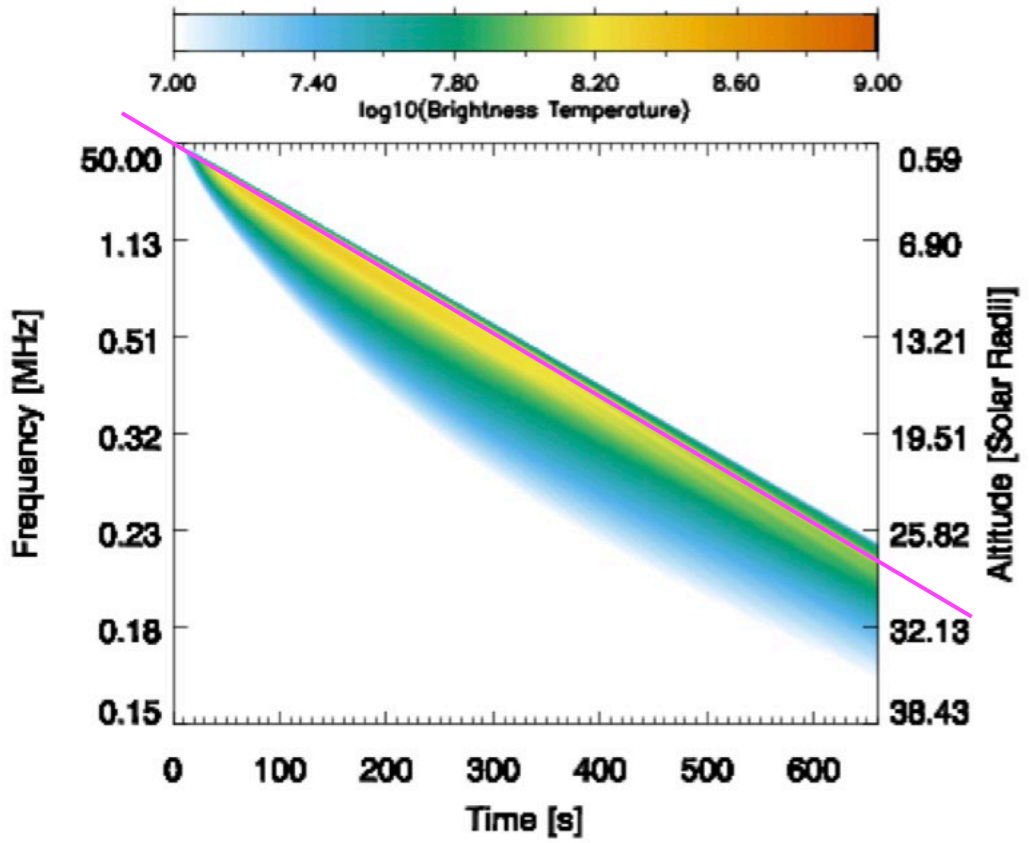
velocity spectral index = α



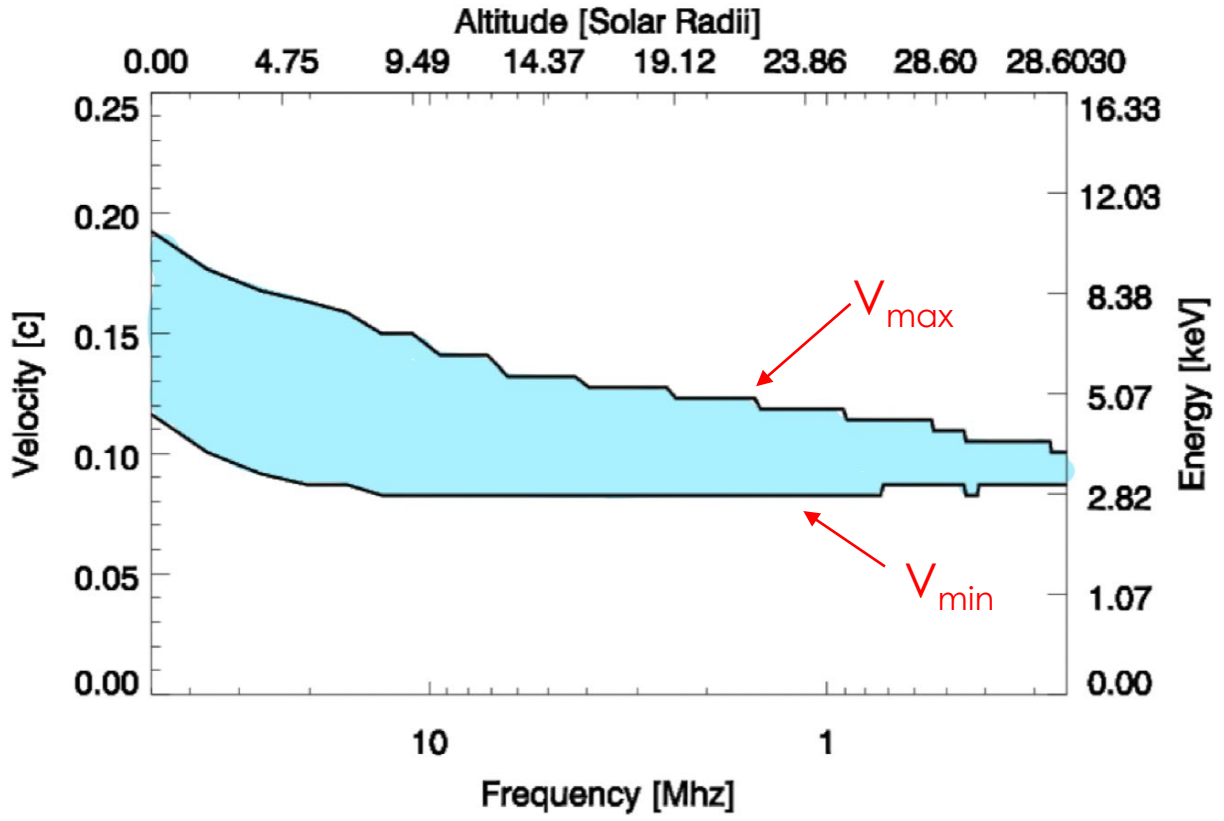
- In our simulated beam the **maximum electron velocity** growing Langmuir waves **decreases as $r^{-0.5}$** as the beam propagates away from the Sun
- **V_{max}** depends on the **beam energy density**
- Beams with **higher initial energy densities** will have a **higher v_{max}**

Main results from project/paper 1 Associated radio emission: type III solar radio burst

4. Type III fundamental solar radio burst associated with the simulated electron beam



5. Electron velocity range growing Langmuir waves as a function of type III frequency

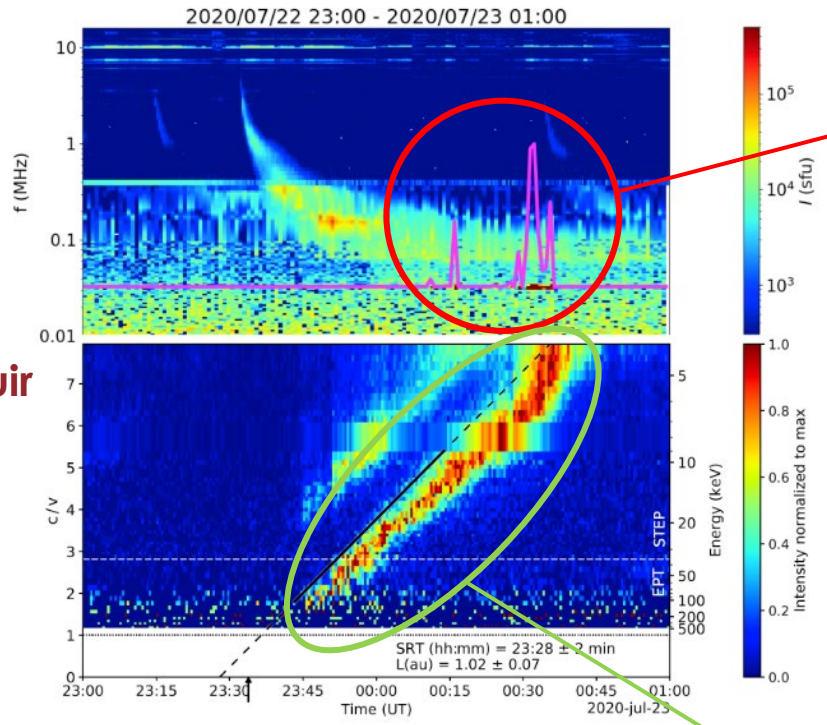


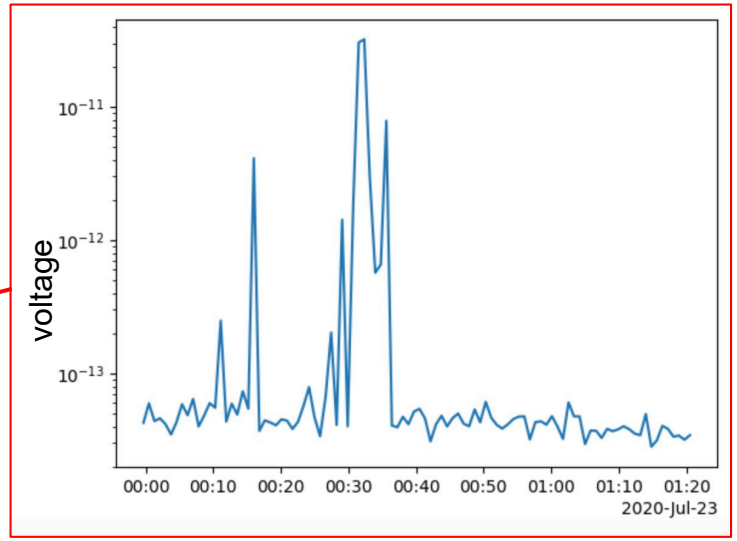
- From **the type III** solar radio burst frequencies we find **Δv = 0.1 close to the Sun.**
- The **velocity range decreases** with **increasing frequency** → artefact of simulation due to **cst v_{th} and T_e?**

RPW data: 23rd July 2020 event

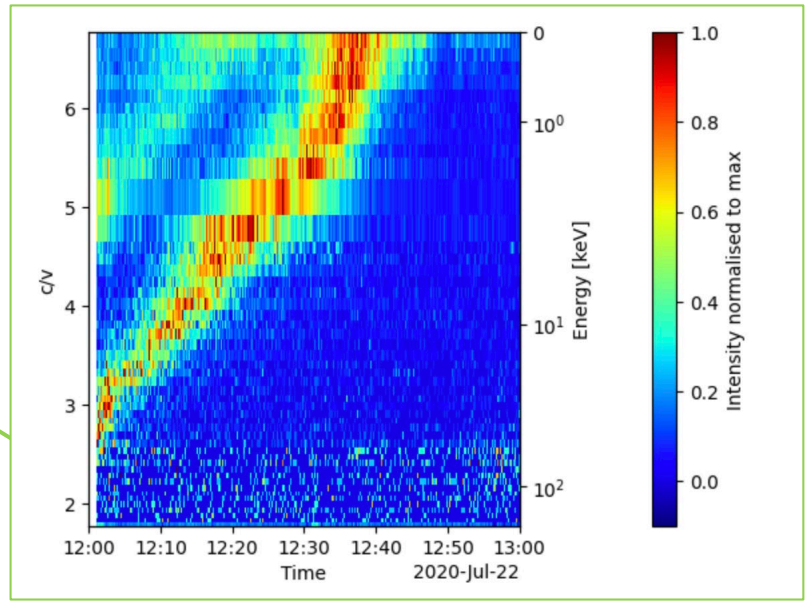
sub-10keV electrons arriving at SolO co-temporal with **Langmuir waves at 0.51AU**

Gomez-Herrero et al. 2021





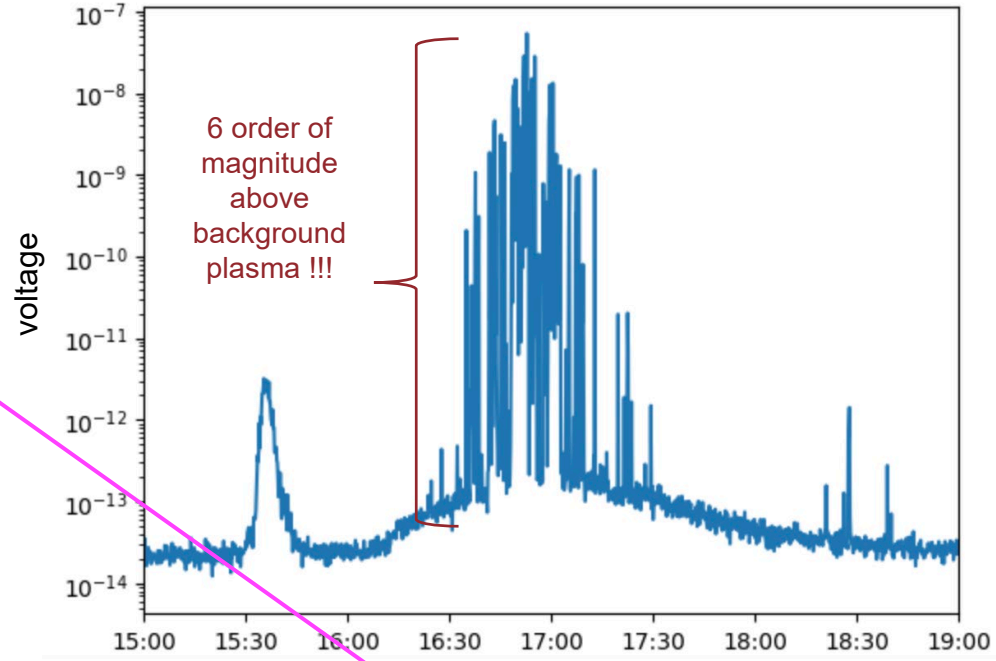
Replicating the Langmuir wave analysis using TNR and BIAS RPW data



Replicating the electron beam analysis using STEP EPD data

RPW data: 28th October 2021 event

- Identify exactly which energy electron arrive with the Langmuir waves (Lorfing and Reid 2022 - submitted)
- Remove the background → make a histogram of the Langmuir wave event
- Look at the solar wind conditions for all events (temperature, density, turbulence, velocity) measured by SWA
- Looking at the temporal profile in each energy channel and identifying evidence for the bump on tail instability



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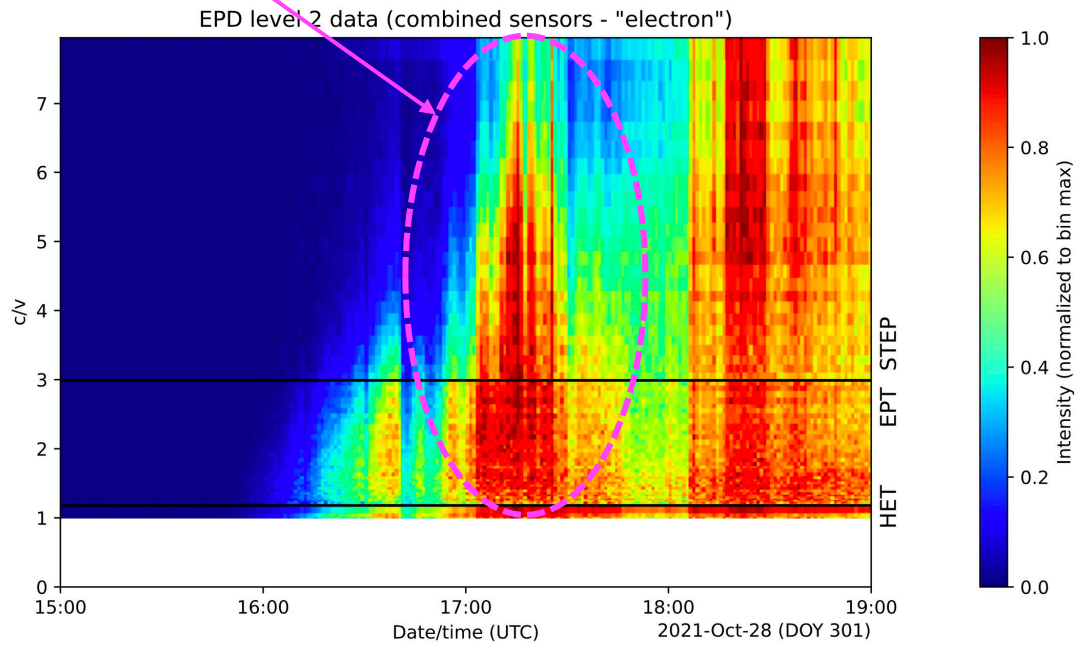

Replicating the electron beam analysis using STEP EPD data