Investigating Langmuir wave growth during type III radio emissions

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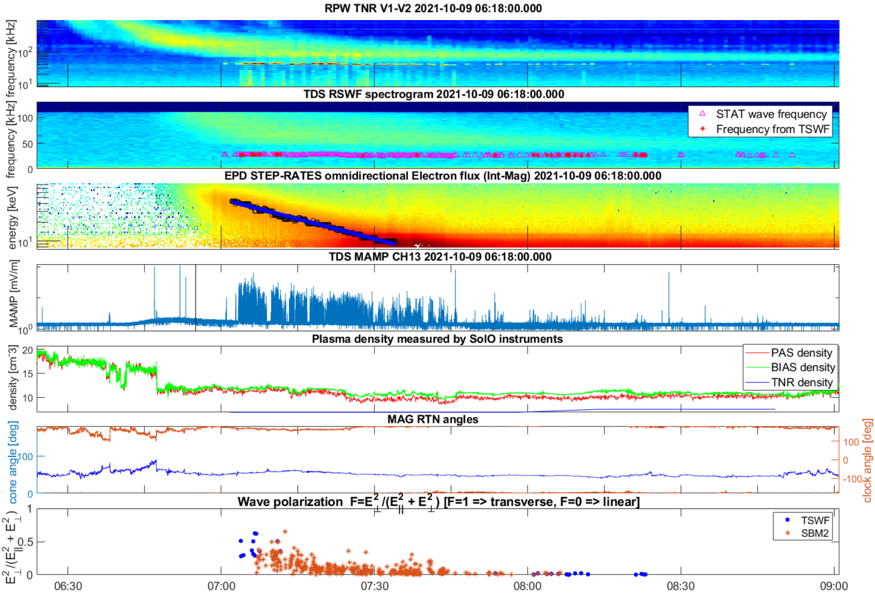
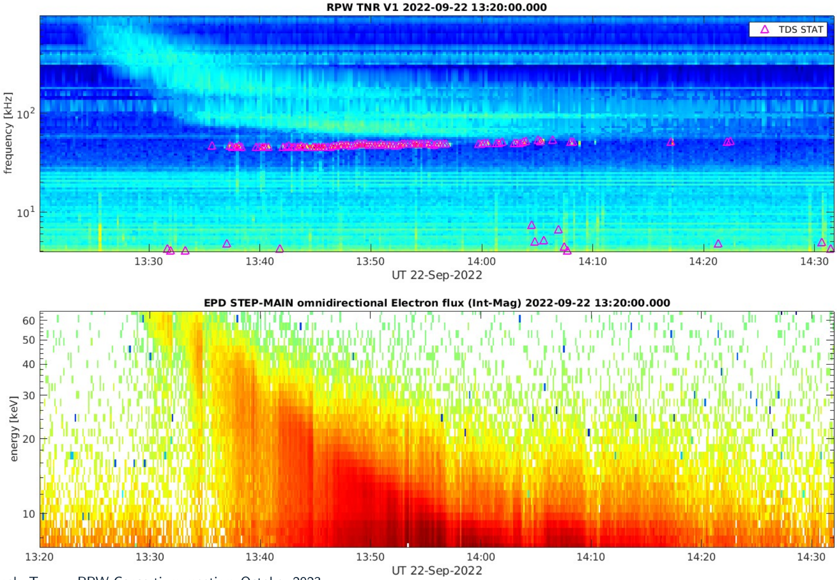
Previous work on Type III events 2021-10-09



Langmuir wave growth



SolO electron observations

- Langmuir waves grow when the electron velocity distribution function (eVDF) is unstable
- To determine the eVDF stability we need to analyze the particle data
- Combining data from SWA-EAS and EPD-STEP

Instrument	Energy range
SWA-EAS	$1\,\mathrm{eV} - 5\,\mathrm{keV}$
EPD-STEP	$\sim 7\,\mathrm{keV} - 80\,\mathrm{keV}$

Table: Electron energy ranges of Solar Orbiters particle instruments

SolO electron observations

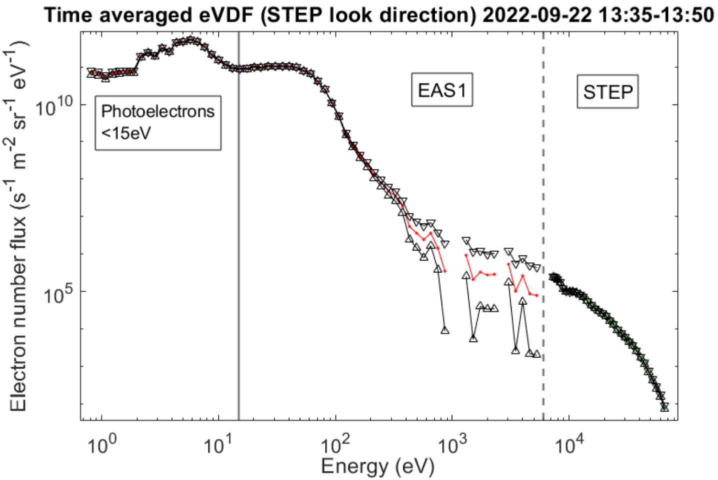


Figure: Time averaged electron flux along the Parker spiral

Fitting electron data

How to determine the eVDF stability?

- Smooth fit which preserves the shape of the eVDF
- High temporal resolution
- Use electron counts (zero count for $> 60\%$ of the data)

Possible approaches

- Time averaging the eVDF data
  - Better count statistics
  - Lower time resolution
- Fitting the beam with a drifting Maxwellian
  - Few fit parameters
  - Constraint on the fitted eVDF shape

Fitting electron data

Smoothing spline fit

- General additive model with interactions
- Preserves the measured eVDF shape
- Least squares fit - as initial guess

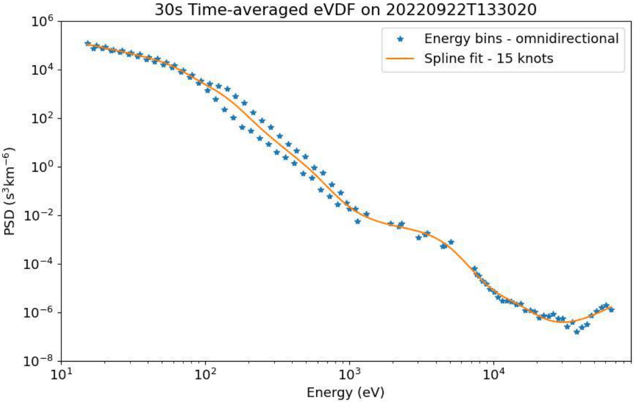
Fitting the logarithm of Phase space density (PSD) as a sum of splines and interaction terms.

$$\log_{10}(PSD) = f_{fit}(v_{\parallel}, v_{\perp}, t) = \beta_0 + s_1(v_{\parallel}) + s_2(v_{\perp}) + s_3(t) + t_1(v_{\parallel}, v_{\perp}) + \cdots$$

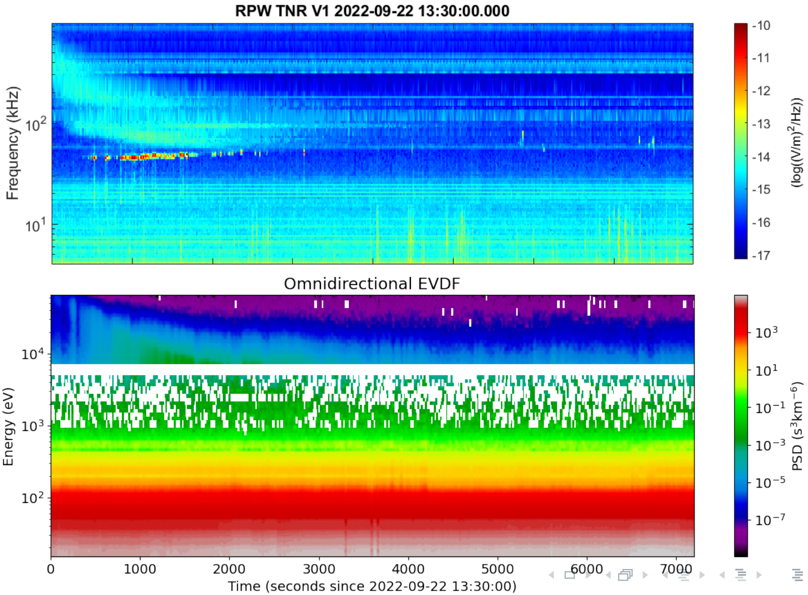
Difficulties and ongoing work

- Zero count data cannot be used for least squares fit.
- An iterative fitting method is needed to take into account the Poisson distribution of the counts.
- Fitting $log_{10}(\mathrm{PSD})$ as a function of $log_{10}(\mathrm{energy})$

1D fitting


30s Time-averaged eVDF on 20220922T133020
Energy bins - omnidirectional
Spline fit - 15 knots
PSD (s^{3}km^{-6})
Energy (eV)
10^6
10^4
10^2
10^0
10^{-2}
10^{-4}
10^{-6}
10^{-8}
10^1
10^2
10^3
10^4

2D data


RPW TNR V1 2022-09-22 13:30:00.000
Frequency (kHz)
10^2
10^1
-10
-11
-12
-13
-14
-15
-16
-17
(log((V/m)^2/Hz))
Omnidirectional EVDF
Energy (eV)
10^4
10^3
10^2
10^3
10^1
10^{-1}
10^{-3}
10^{-5}
10^{-7}
PSD (s^{3}km^{-6})
0
1000
2000
3000
4000
5000
6000
7000
Time (seconds since 2022-09-22 13:30:00)

2D data

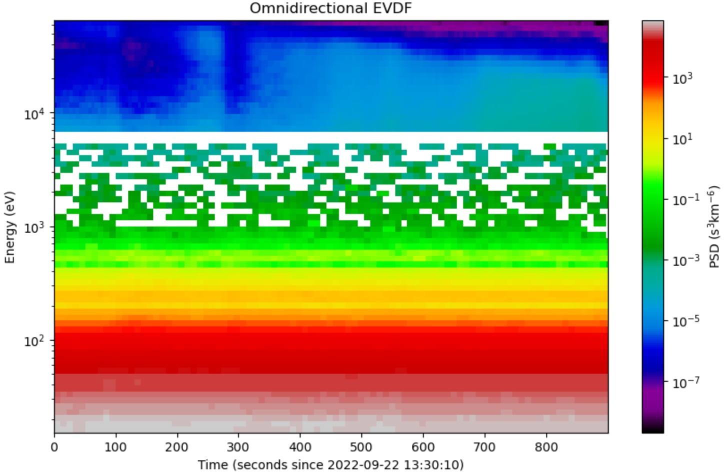


Figure: Zoomed in view on the electron beam

2D fitting

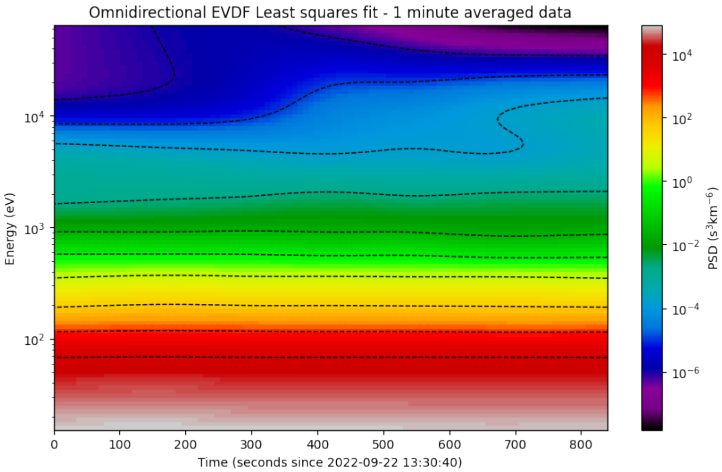


Figure: Least squares spline fit of the averaged electron data

Future work

- Improve the fitting procedure assuming the Poisson probability distribution of counts.
  Minimizing μ, summing over all observations. [Santolík, 1990]

$$\mu(\beta) = \sum_{i=1}^{m} [n_i(\beta) - N_i \ln(n_i(\beta))] \quad (1)$$

  $n_i(\beta)$ - predicted count
  $N_i(\beta)$ - observed count

- Determine the stability using the fit
- Compare the resulting stability with RPW wave observations

Determining eVDF stability

- Use the Penrose criterion [Gurnett and Bhattacharjee, 2005]

$$F_0(v_\parallel, t) = \frac{1}{n_0} \int_0^{2\pi} \int_{-\infty}^{\infty} f_0(\mathbf{v}, t) v_\perp \, dv_\perp \, d\varphi \tag{2}$$

$$\int_{-\infty}^{\infty} \frac{F_0(v_\parallel, t) - F_0(V_j, t)}{(v_\parallel - V_j)^2} dv_\parallel > 0 \tag{3}$$

- Use a numerical dispersion relation solver

Figure: The Arbitrary Linear Plasma Solver [Verscharen et al., 2018]

Comparison with MAMP

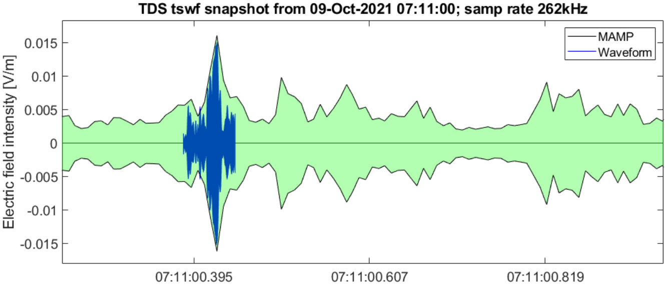


Figure: TDS MAMP data can be used to compare our result with observations

Literature

D. A. Gurnett and A. Bhattacharjee. *Introduction to Plasma Physics: With Space and Laboratory Applications*. Cambridge University Press, 2005. ISBN 9780521364836.

O. Santolík. Studium rozdělovací funkce plazmatu a vlnové rozdělovací funkce v kosmickém prostoru. *Disertační práce, MFF UK, Praha*, 1990.

D. Verscharen et al. Alps: the arbitrary linear plasma solver. *Journal of Plasma Physics*, 84(4):905840403, 2018. doi: 10.1017/S0022377818000739.

Any Questions?