Analysis of type III radio emissions observed by the Solar Orbiter spacecraft close to their source locations

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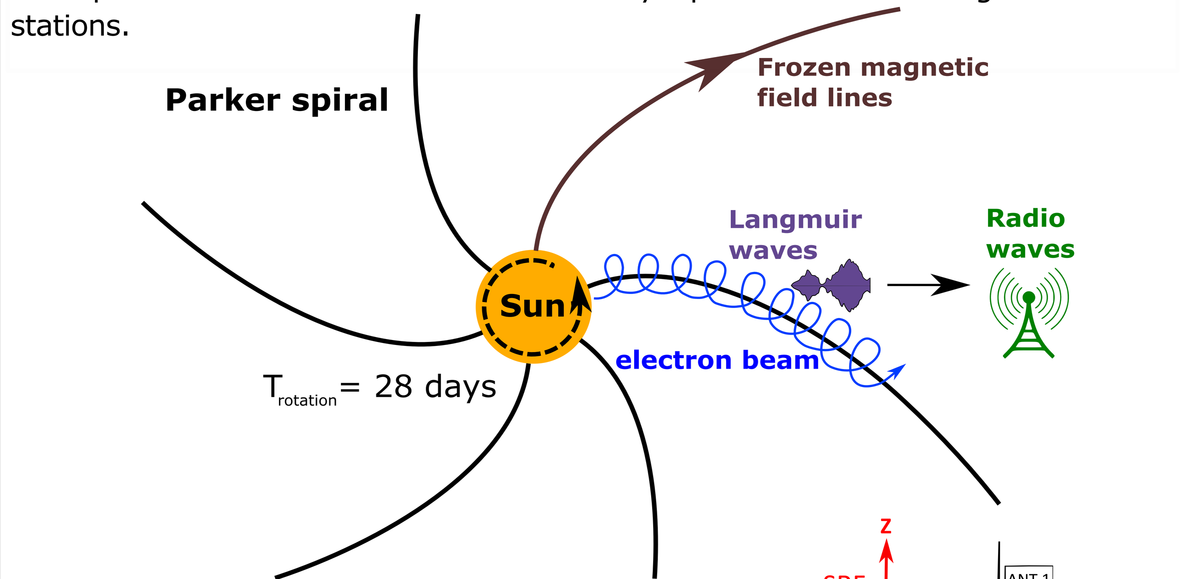
Introduction

Type III radio emissions are common phenomena in the solar wind. They are caused by an electron beam which is ejected from the Sun. The beam then travels along the magnetic field lines and locally generates Langmuir waves. The Langmuir waves are then converted into a radio emission at the local plasma frequency or its first harmonic frequency. These radio waves can propagate at the free-space mode and can be observed by spacecraft or even ground based stations.



In this analysis we study in-situ type III events observed by the Solar Orbiter (SolO) spacecraft. We detect these events with data from several instruments onboard the spacecraft. We use data from the Time Domain Sampler (TDS) and the Thermal Noise Receiver (TNR) subsystems of the Radio and Plasma Waves (RPW) instrument. The Energetic Particle Detector (EPD) allows us to directly observe the electron beam.

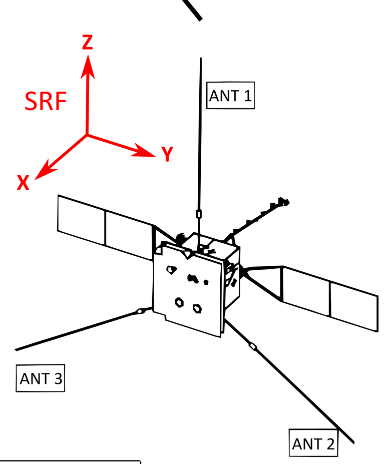


Figure showing the three electric antennas of the Solar Orbiter relative to the spacecraft reference frame (SRF).

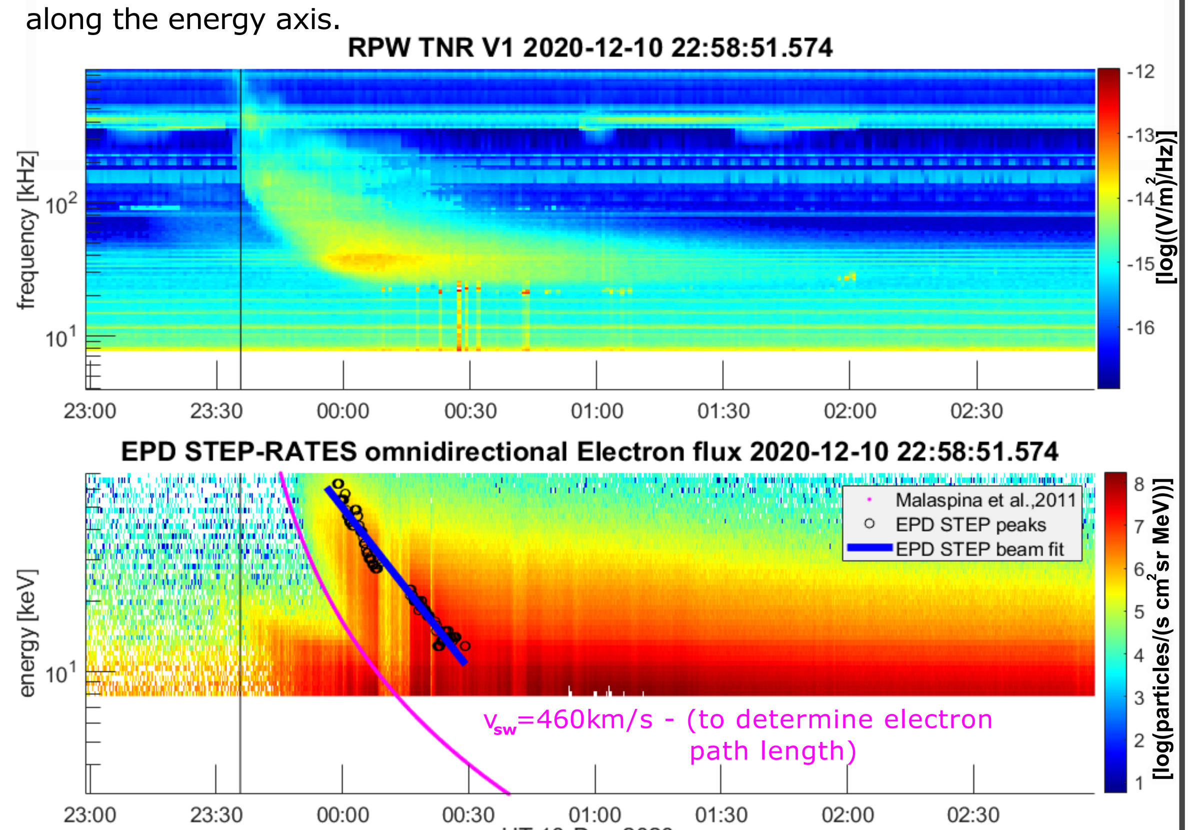
	Type of data	Frequency range	Measurement
TDS RSWF-e	Regular electric waveform	200 Hz – 200 kHz	Typically, every 5 minutes
TDS TSWF-e, SBM2-e	Triggered electric waveform	200 Hz – 200 kHz	Triggered by onboard algorithm
TDS STAT	Statistics		Every 1 second
TNR	Spectrum	4 kHz – 1 MHz	About every 2 seconds

Table 1: Summary and description for the used data from RPW

Electron beam speed

Using the Energetic Particle Detector (EPD) one can directly observe the passing electron beam. We compare the data from the Suprathermal Electrons Protons (STEP) subsystem (energy range of 2-80keV) to the predicted beam speed calculated as distance over time. In this prediction we use the distance along the Parker spiral and the time since the type III radio emission started.

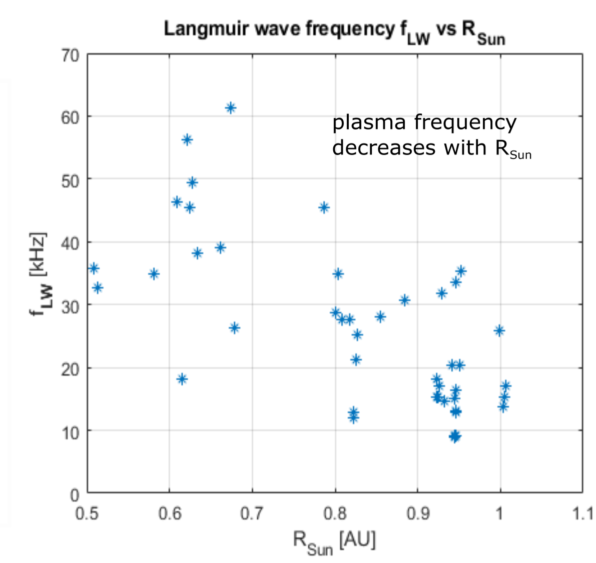
This method was used in earlier works such as Malaspina et al., 2011. Our analysis of all in-situ events shows that the predicted speed is lower by (9±4) keV compared to the STEP data. The STEP data was fitted by finding the peaks along the energy axis.



Statistical analysis

In our analysis, we studied the effects of the solar wind plasma parameters on type III events. We focused on the effect of parameters such as electron beam speed, wave energy, plasma electron density, distance from the Sun, and magnetic field, on wave polarization. Additionally, we examined the interdependence of these parameters.

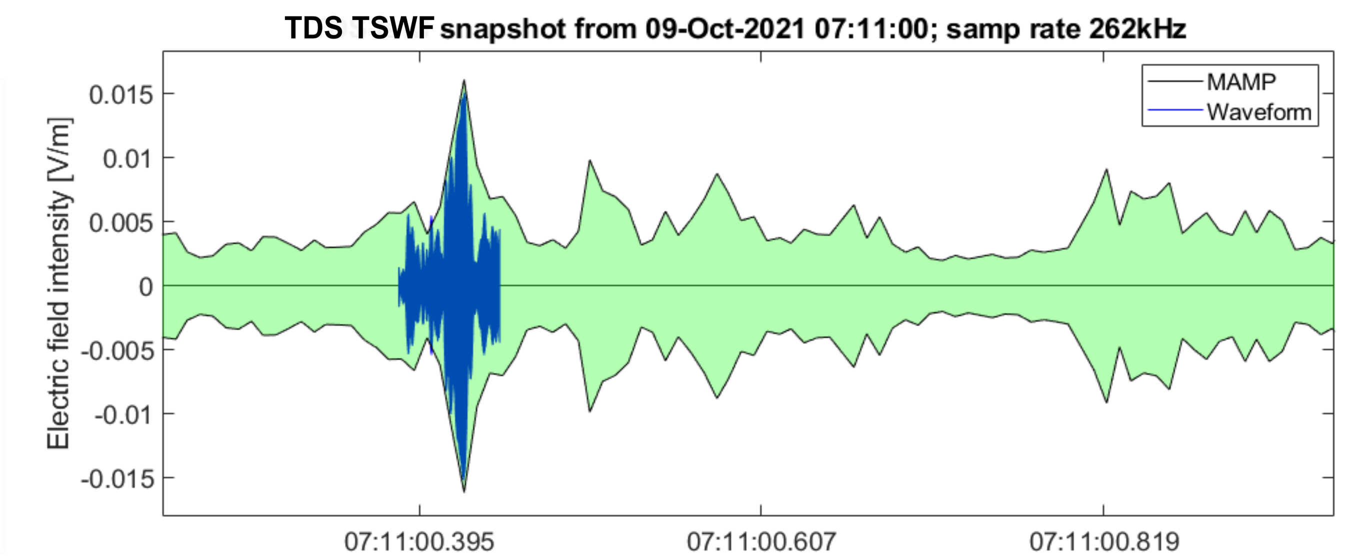
For the statistical analysis we selected 74 events type III events observed by TDS, and to study the wave polarization we narrowed our focus to in-situ events (Langmuir waves present or visible electron beam by EPD) with a distinct electron beam (can be fitted) in the EPD data. All the in-situ events are listed in table 2.



MAMP wave packet tracking

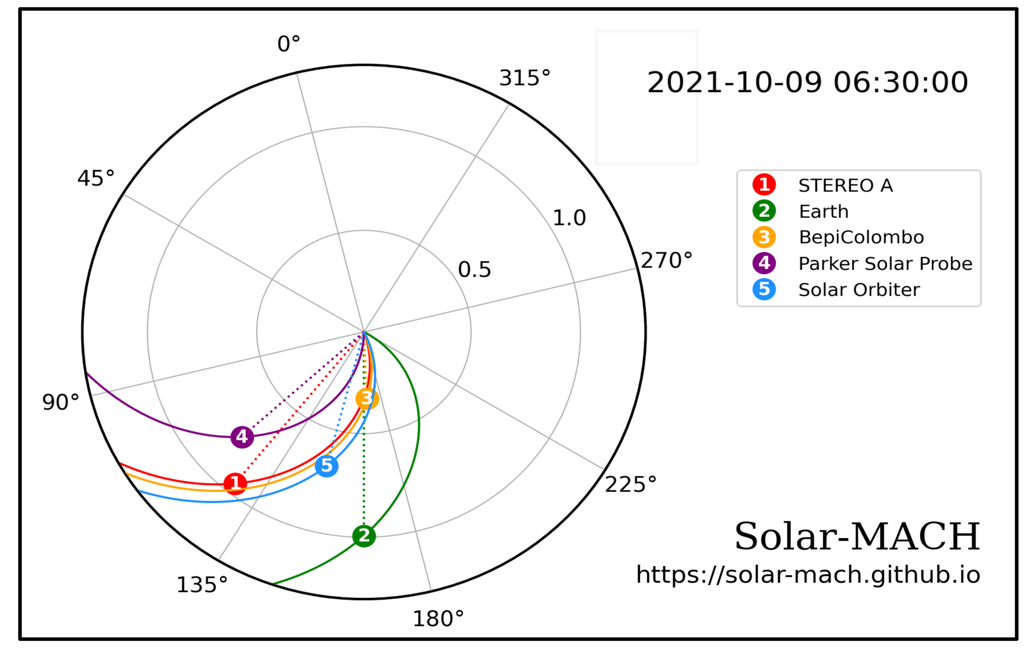
The maximum amplitude (MAMP) data from the TDS receiver are continuously sampled at the cadence of 2097.1 ksps and saved every 7.8-250ms. The amplitudes are taken directly from the antennae without additional digital filtering. We show that the MAMP data can be used to track the wave packet envelopes of Langmuir waves.

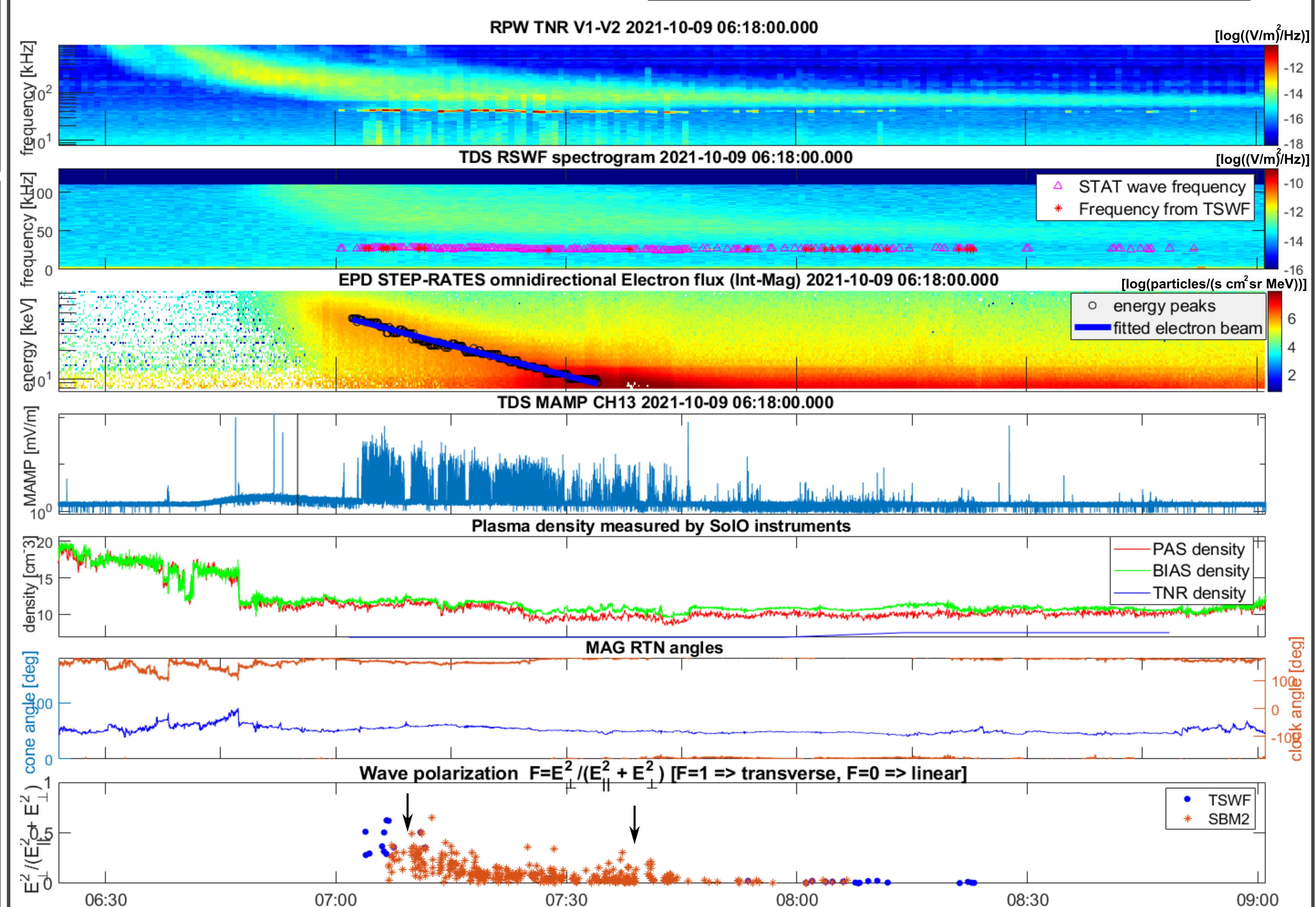
Since the TDS waveform snapshots only last up to 63 ms, we can use MAMP data to look beyond the snapshots. Assuming that Langmuir waves are the most intense emission during the in-situ type III events, one can consider the measured MAMP amplitudes as Langmuir wave amplitudes. We can then determine the presence of Langmuir waves by using MAMP data. This way we can detect Langmuir waves over larger timescales. For this reason, the MAMP data is included in the overview panels for each in-situ type III event.



Overview panels

An example of detailed analysis for the in-situ type III event observed on October 9, 2021. By combining data from several onboard instruments we created overview panels for all observed type III events. The first two panels shows a time frequency spectrogram, first from RPW TNR and the second from TDS overlayed with TDS STAT data. The third panel shows the EPD STEP electron energy spectrogram, with a fitted electron beam. The fourth panel shows TDS MAMP data which can help us indicate the presence of Langmuir waves. The fifth and sixth panels show the solar wind parameters, namely the plasma density and magnetic field data. The last panel shows the Langmuir wave polarization.





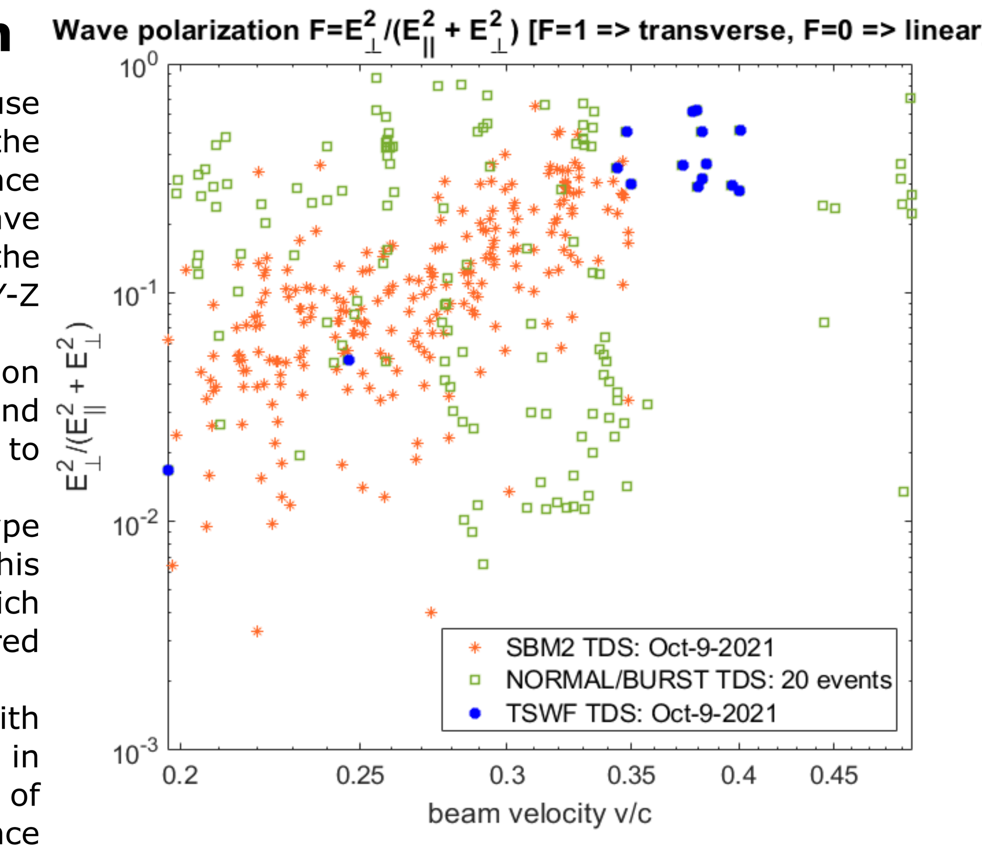
Langmuir wave polarization

To study the Langmuir wave polarization we use the Magnetometer (MAG) data. By projecting the magnetic field onto the Y-Z Spacecraft Reference Frame (SRF) plane, we can obtain the wave component parallel and perpendicular to the projection of the magnetic field onto the Y-Z plane.

We are able to determine the wave polarization for 21 events with both magnetic field data and EPD electron beam speed data from July 2022 to March 2022.

A detailed analysis is shown for the in-situ type III event which occured on October 9, 2021. This event was recorded in the SBM2 mode, which provides us with a higher cadence of captured waveform snapshots for the entire event.

We found that wave polarization correlates with the electron beam speed; faster beams result in more oblique wave polarization. Due to the lack of the high cadence observations, such dependence is not clearly visible in the NORMAL mode observations.



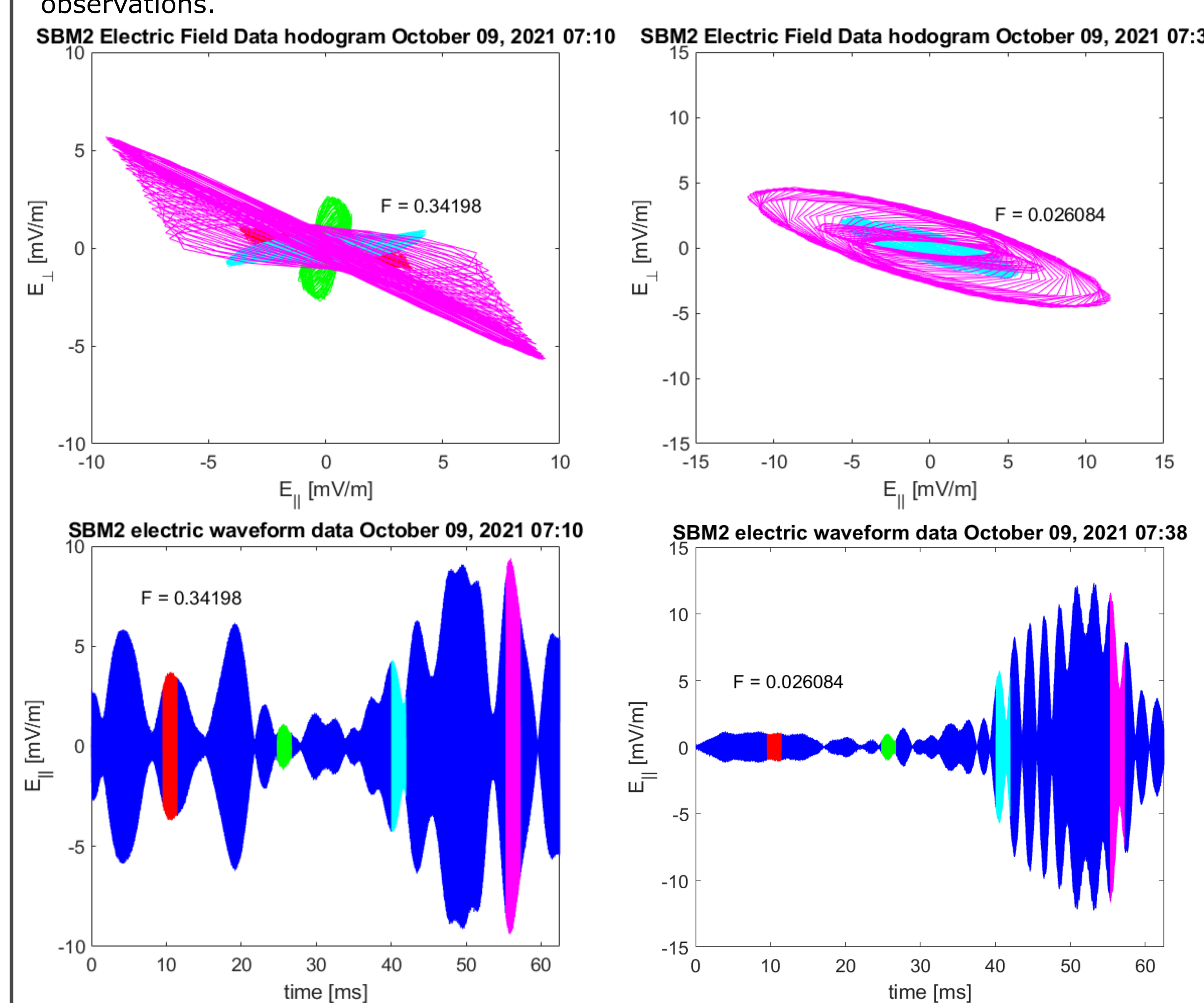


Table 2: All analyzed in-situ type III events seen by TDS (Jul 2020 -Mar 2022).

date	f [kHz]	visible beam	R_{Sun} [Au]
2020-07-20 20:10	61.4	0	0.67
2020-11-17 01:50	31.7	0	0.93
2020-11-17 18:30	17.1	1	0.93
2020-11-18 11:00	15.4	0	0.92
2020-11-18 13:40	15.4	1	0.92
2020-12-10 07:20	21.2	1	0.83
2020-12-10 20:20	12.1	1	0.82
2020-12-10 23:40	12.9	1	0.82
2020-12-13 09:00	27.6	0	0.81
2021-03-05 16:30	35.0	1	0.58
2021-04-20 00:20	28.2	0	0.85
2021-05-09 14:00	18.3	0	0.92
2021-05-21 23:05	15.0	1	0.95
2021-05-22 01:30	9.0	1	0.95
2021-05-22 03:00	9.0	1	0.95
2021-05-22 03:50	9.2	1	0.95
2021-05-22 06:55	9.1	1	0.95
2021-05-22 14:20	33.5	0	0.95
2021-05-22 15:20	33.5	0	0.95
2021-05-23 04:40	16.4	1	0.95
2021-05-23 09:30	12.9	1	0.95
2021-05-23 11:10	13.2	1	0.95
2021-05-28 23:45	20.3	0	0.95
2021-07-24 00:12	27.6	0	0.82
2021-08-24 13:25	38.1	1	0.63
2021-08-26 18:30	45.3	1	0.62
2021-09-26 11:45	18.3	1	0.62
2021-10-06 04:00	39.0	1	0.66
2021-10-09 06:48	26.4	1	0.68
2021-10-28 15:40	35.0	0	0.80
2021-11-01 01:30	25.3	0	0.83
2021-11-09 17:20	30.7	0	0.88
2021-12-04 07:55	13.8	1	1.00
2021-12-04 13:30	15.4	1	1.00
2021-12-06 05:45	17.1	1	1.01
2021-12-31 10:10	25.8	1	1.00
2021-12-31 12:50	-	1	1.00
2022-01-12 07:15	-	1	0.96
2022-01-14 13:40	35.4	1	0.95
2022-01-16 19:55	20.3	1	0.94
2022-01-18 17:55	14.7	1	0.93
2022-02-07 06:50	28.8	0	0.80
2022-02-07 19:20	-	1	0.80
2022-02-08 21:45	45.3	0	0.79
2022-03-05 23:55	32.8	1	0.51
2022-03-06 08:23	35.7	1	0.51

Conclusions

Our investigation focuses on in-situ type III events observed by the Solar Orbiter spacecraft from July 2020 until March 2022. We compiled a list of these events and generated quicklooks of fields and particle observations for each one. We conducted a statistical analysis to examine the role of several plasma parameters in generating in-situ plasma waves.

To evaluate the accuracy of a previously used model for predicting electron beam speed during in-situ type III events, we used the EPD STEP data to fit observed electron beams in the energy spectrograms. Comparing the fits to the predicted beam speed, our analysis indicates that the model underestimates the electron beam speed. This suggests that electron beams may not propagate at a constant speed or along the Parker spiral.

Our statistical analysis revealed no correlation between the collected statistics data and wave polarization in the NORMAL/BURST data. However, based on SBM2 data from the October 9, 2021 in-situ event, we found that wave polarization is dependent on the electron beam speed. Unfortunately, this event was the only event both recorded in SBM2 mode and with sufficient MAG and EPD data for our analysis. Nevertheless, we plan to continue analyzing other in-situ events as more data becomes available.

We showed how MAMP data can be used to track the wave packet envelopes of Langmuir waves and detect their presence. This expands the capabilities of the RPW instrument beyond snapshot-based waveform analysis.