DEPARTMENT OF SPACE AND CLIMATE PHYSICS,
MULLARD SPACE SCIENCE LABORATORY

UCL

Investigating the mechanisms driving electron flat top distributions in IP shocks:

UCL MSSL

ESA | NASA solar orbiter

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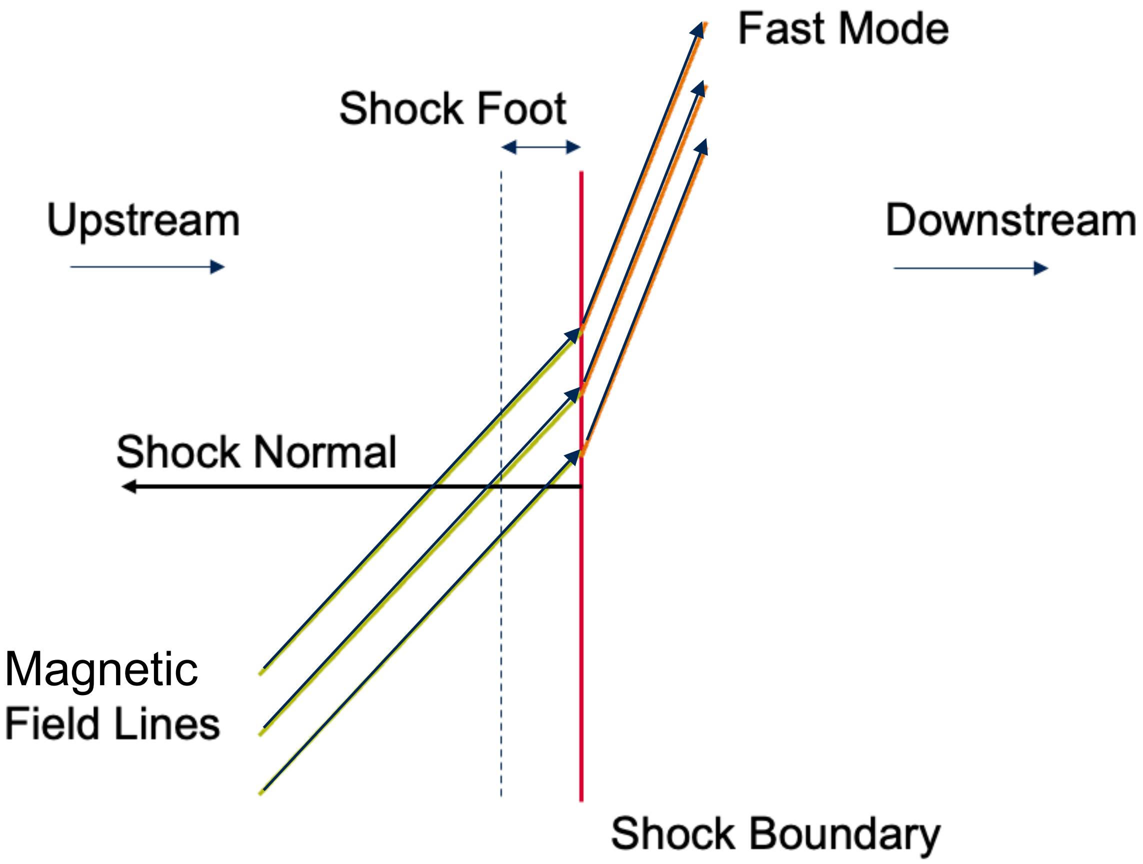
Magnetosonic Shocks

- Magnetosonic shocks occur when the upstream flow speed is faster than the magnetosonic speed.
- A discontinuity forms in the plasma parameters.
- Jump conditions: based on change in pressure, velocity, density, flow of magnetic field and flow of mass across the boundary.
- Different types of shock exist based on geometries of the shock and changes to the jump conditions.
- Electrons are heated and accelerated at shocks.



Shock Detection

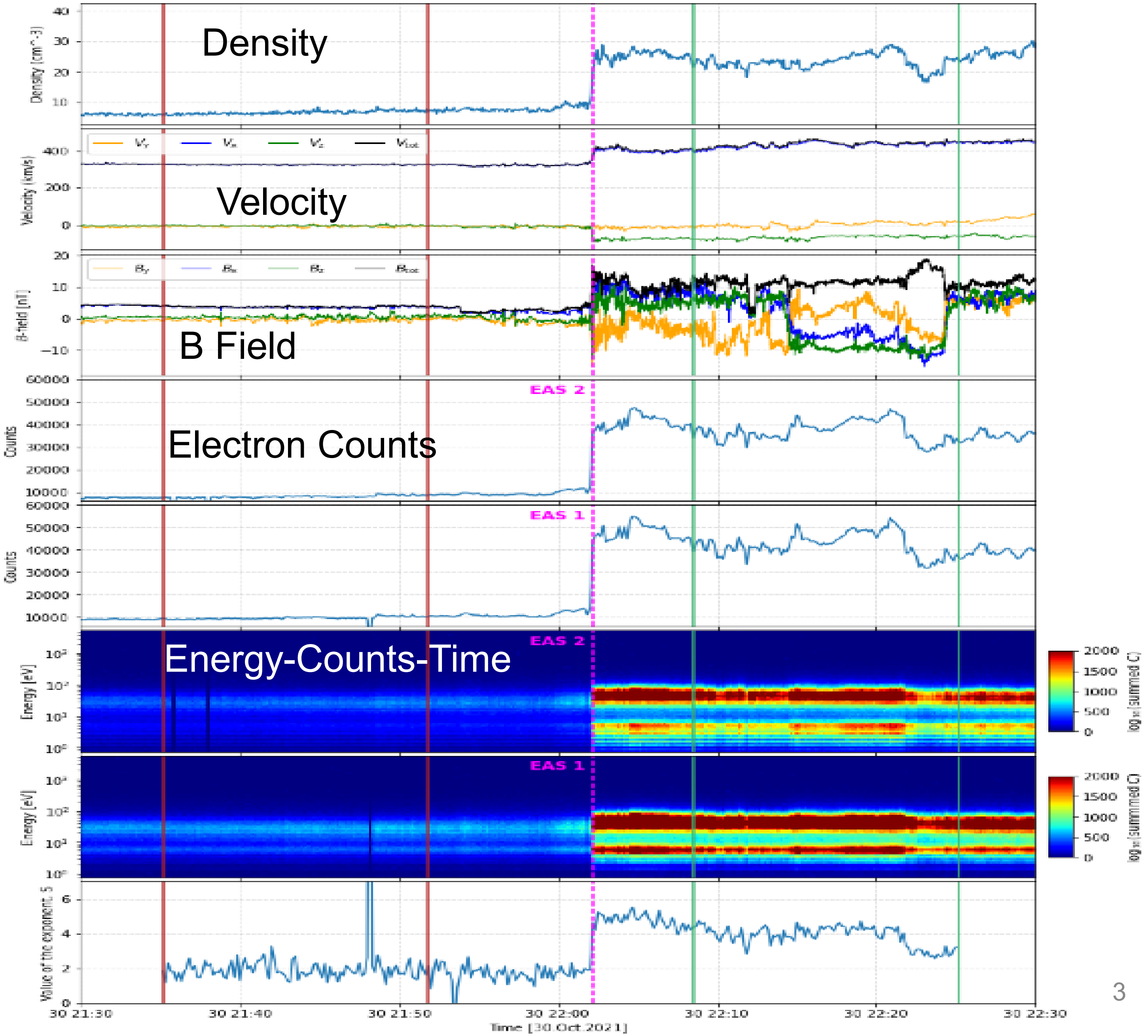
Rankine-Hugoniot Equations:

$$[B_n] = 0$$

$$[nv_n] = 0$$

$$nmv_n[v_n] = -[p + \frac{B^2}{2\mu_0}]$$

$$nmv_n[\vec{V}_t] = \frac{B_n}{\mu_0}[\vec{B}_t]$$



Shock Characterization

- Equations for the angle between the shock normal and magnetic field (θ*Bn*), the Alfvén speed (*VA*), Alfvén Mach number (*MA*), gas compression ratio (*rgas*), magnetic compression ratio (*rB*), sound speed (*Cs*), upstream plasma beta (β) and electron temperature (*Te*). These parameters were either directly used in analysis or were used in the process of calculating other parameters.
- This was done for 38 shocks detected by the Solar Orbiter between June 2021 to February 2023.

$\theta_{Bn} = \arccos \frac{\mathbf{B}_u \cdot \mathbf{n}}{\lvert\mathbf{B}_u\rvert}$	$V_A = \frac{B}{\sqrt{\mu_0 N_p}}$	$M_A = \frac{\lvert\mathbf{v_u} \cdot \mathbf{n}\rvert}{V_A}$	$r_{gas} = \frac{n_d}{n_u}$
$r_B = \frac{B_d}{B_u}$	$C_s = \sqrt{\gamma k_B \frac{T_P + T_e}{m_p}}$	$\beta = \frac{2 k_B \mu_0 N_P (T_P + T_e)}{B^2}$	$T_e = T_0 + T_1 r^{-\frac{4}{3}}$

The relation between interplanetary shock properties and the occurrence of flat top electron distributions

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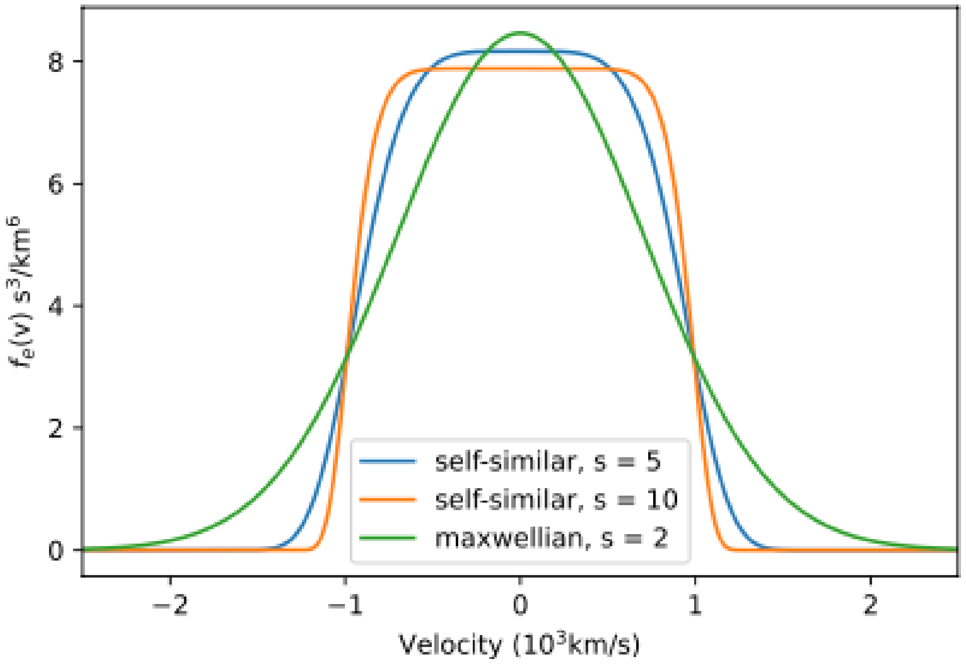
-What is the relationship between shock properties and the degree of flatness in a flat top distribution?
-What are the mechanisms involved in driving electrons across a shock to form this distribution?
-To what extent do certain shock parameters affect the shape of the distribution?
-Are there any shock parameters that affect the distribution that could highlight other mechanisms involved?

HOW DO SOLAR TRANSIENTS DRIVE HELIOSPHERIC VARIABILITY?

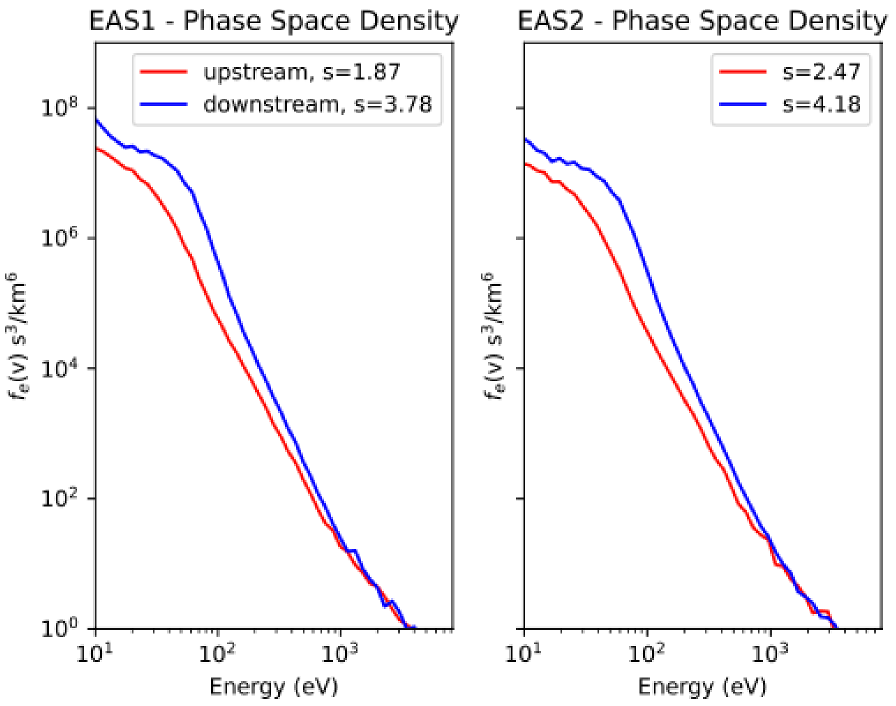
Flat top distribution:

- Electrons upstream exhibit a Maxwellian distribution
- Downstream, a distribution with a plateaued region between 20 to 500 eV can develop.
- This is thought to be because of the potential of the electric field and waves generating instabilities to drive and accelerate the electrons
- The self-similar distribution function describes the upstream and downstream distributions.
- The exponent, “s” governs the flatness of this function.
- A higher s value produces a flatter top distribution, notably s=2 is Maxwellian.



$$f_s(v,t) = \frac{n_o\ s}{2\ V_{T_s}\ \Gamma(1/s)}\ e^{-\left(\frac{v}{V_{T_s}}\right)^s}$$

Example shock:



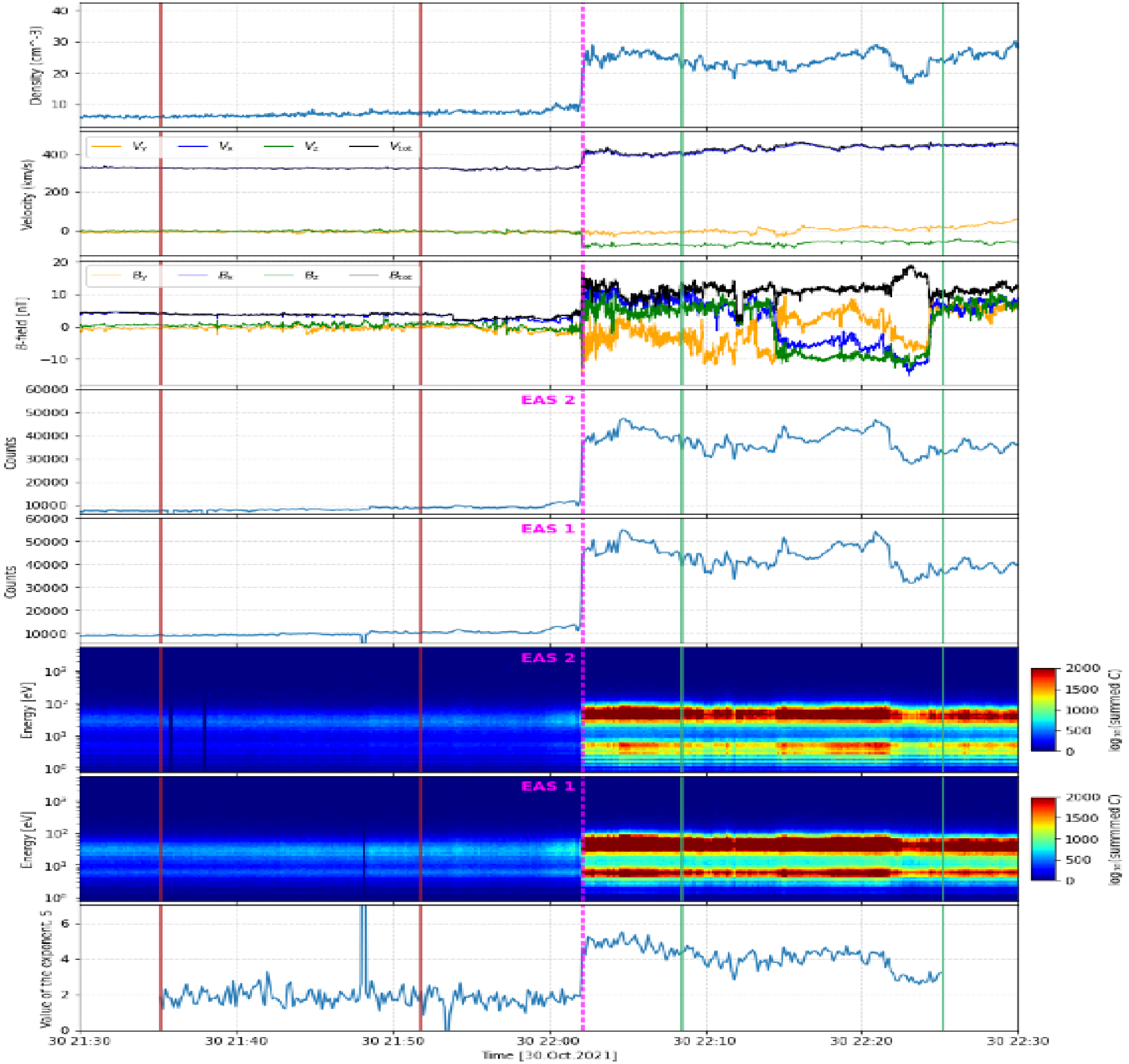


Table of results:

- A subsection of the results table showing the parameters of some shocks as well as the correlation coefficients and P values calculated by the statistical tests for all the 38 shocks.

Shock Date	dS	θ_{Bn}	Heliocentric distance	Alfven Speed	Shock Speed	MA	rGas	rB
(dd-mm-yy)	-	(∘)	(Au)	(Km/s)	(Km/s)	-	-	-
13-Jun-21	**1.67**	76.9	0.95	47	376	2.9	1.47	1.48
30-Oct-21	**3.78**	80.2	0.82	32	403	4.98	3.82	3.09
03-Nov-21	**1.74**	73	0.84	68	351	1.46	1.6	1.43
03-Nov-21	**2.65**	72	0.84	75	229	1.14	3.84	2.15
16-Nov-21	**1.07**	85.8	0.92	40	-154	3.89	1.41	1.69
16-Feb-22	**1.54**	59.8	0.71	77	413	1.49	1.4	1.13
21-Feb-22	**2.75**	36.7	0.66	63	426	1.94	1.75	1.67
08-Mar-22	**2.28**	62.2	0.48	97	369	1.2	1.9	1.46
08-Mar-22	**1.81**	69.8	0.48	34	-408	2.28	3.86	2.38
11-Mar-22	**2.33**	28.1	0.44	120	779	3.73	2.71	1.7
03-Apr-22	**2.86**	74	0.36	91	620	2.35	2.18	1.58
08-Apr-22	**3.12**	19.1	0.42	52	384	4.12	2.17	2.2
13-May-22	**2.17**	79.1	0.81	46	463	2.2	1.68	1.68
21-May-22	**2.21**	86.1	0.87	19	413	7.8	1.61	3.56
10-Jun-22	**2.31**	37.4	0.97	50	609	2.7	1.92	1.54
28-Jun-22	**4.85**	42.9	1.01	39	667	6.78	2.83	3
21-Jul-22	**1.99**	58.9	0.99	35	279	1.47	1.8	1.42
r		**-0.35**	**0.00**	**-0.07**	**0.47**	**0.46**	**0.52**	**0.58**
P value		**0.17**	**0.96**	**0.79**	**0.06**	**0.06**	**0.03**	**0.02**

Results

- Previous work has shown stronger shocks exhibit flatter top distributions.

- We have added to this work as the magnetic and gas compression ratios have a positive correlation of 0.58 and 0.52 with the downstream s value, respectively.

- As their P values are below 0.10 this indicates a statistically significant correlation.

- We show the influence these factors have on the degree of flatness, thus how much they affect the mechanisms involved in generating the flat top distribution.

- Other parameters including heliocentric distance or shock geometry show no statistically significant correlation with the degree of flatness which indicates other mechanisms are not important in the development of the flat top distribution.

- Therefore, we have shown which shock parameters affect electron distributions downstream of shocks and to what degree they have an effect.

The development of a flat top distribution:

There are two mechanisms thought to be responsible for the development of flat top distributions in the downstream region for electrons:

Across the shock boundary there is a cross-shock potential caused by the electric field which accelerates electrons along the magnetic field lines.

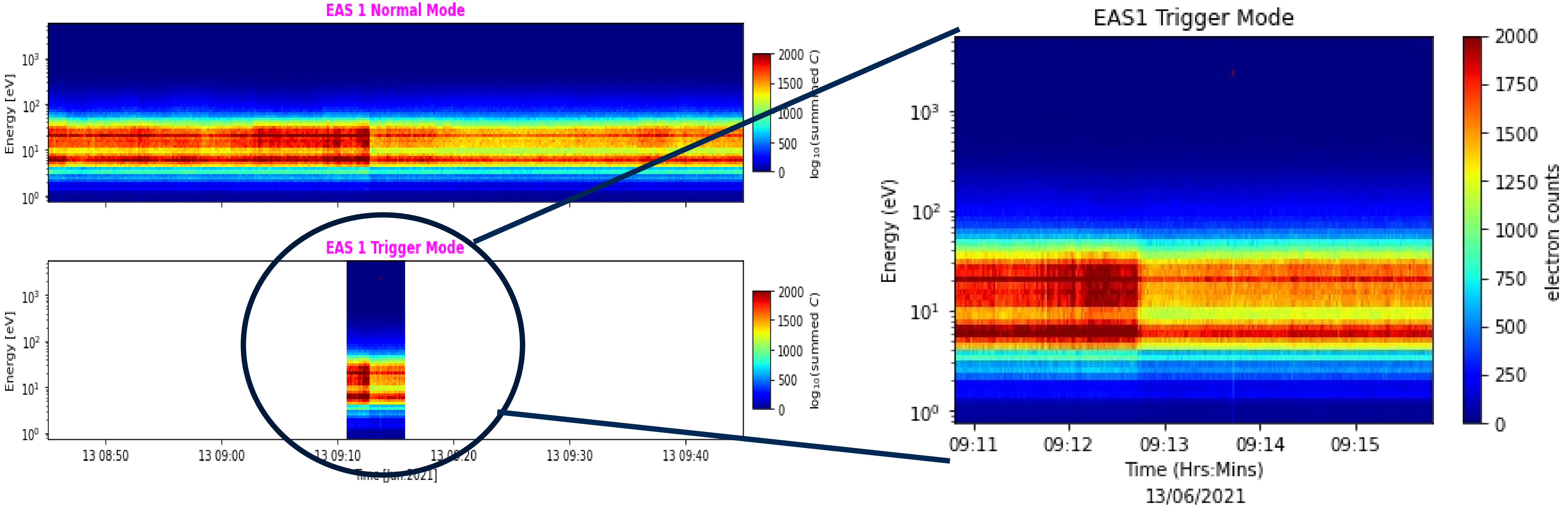
Ion-acoustic waves and whistler waves in the upstream region generate instabilities which scatter the electrons.

Both mechanisms are supported by our first study with IAW amplitudes and cross-shock E field magnitudes increasing with stronger shocks.

- Over what time scales do flat top distributions develop and what does this indicate about the scales over which electrons are heated?
- Along which directions do the flat top shapes first generate?
- Which region does the flat top first begin to develop in?
- To what extent are whistler waves responsible for driving the electrons?
- Which mechanism is the primary cause of defining the flatness of an electron flat top distribution?

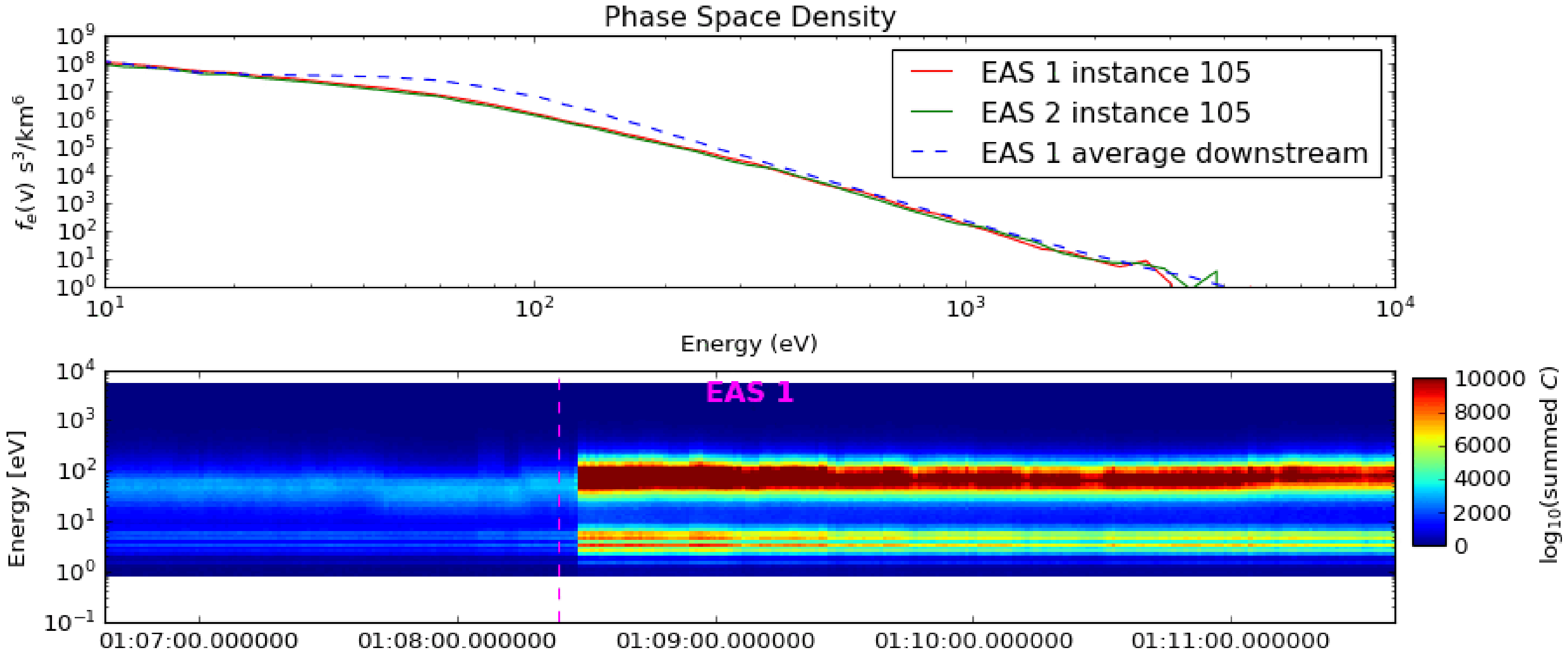
Trigger mode:

- Use the SWA-EAS trigger mode to look closely at these regions and identify where the flat top develops.
- 1 second full 3D distribution compared to the 100 seconds in the normal mode.
- We have some really promising data.
- Much of the data that we respond to RPWs trigger on is not a shock.



Current work:

- Identified a trigger mode shock on 13th March 2023.
- Characterized the event using our automated shock algorithm.
- Examined the transformation of the shape of the 1D distribution function.
- Compared successive fits of the self-similar distribution to identify how the ‘s’ exponent changed.



Next steps:

- Identify whistler precursors before the shock ramp.
- Perform MVA to see the direction the precursors propagate with respect to the shock normal and coplanarity plane.
- Observe along which directions the flat top develops using our high cadence trigger and testing along different elevations and azimuths.
- Determine whether there is a link between the direction of propagation of the precursors and the development of flat top distributions.

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