On the nature and origin of bipolar structures in the Earth's bow shock

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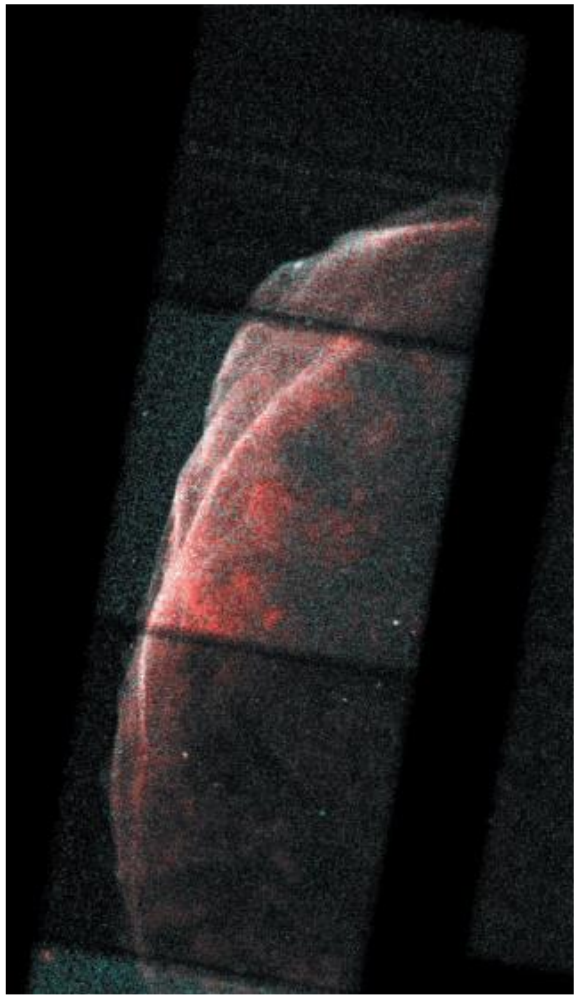
Vasko et al. (2020), *Frontiers in Physics*, https://doi.org/10.3389/fphy.2020.00156

Wang et al. (in prep for JGR)

astrophysical shocks

Chandra measurements
of synchrotron emission in a SNR



Bamba+, ApJ, 2003

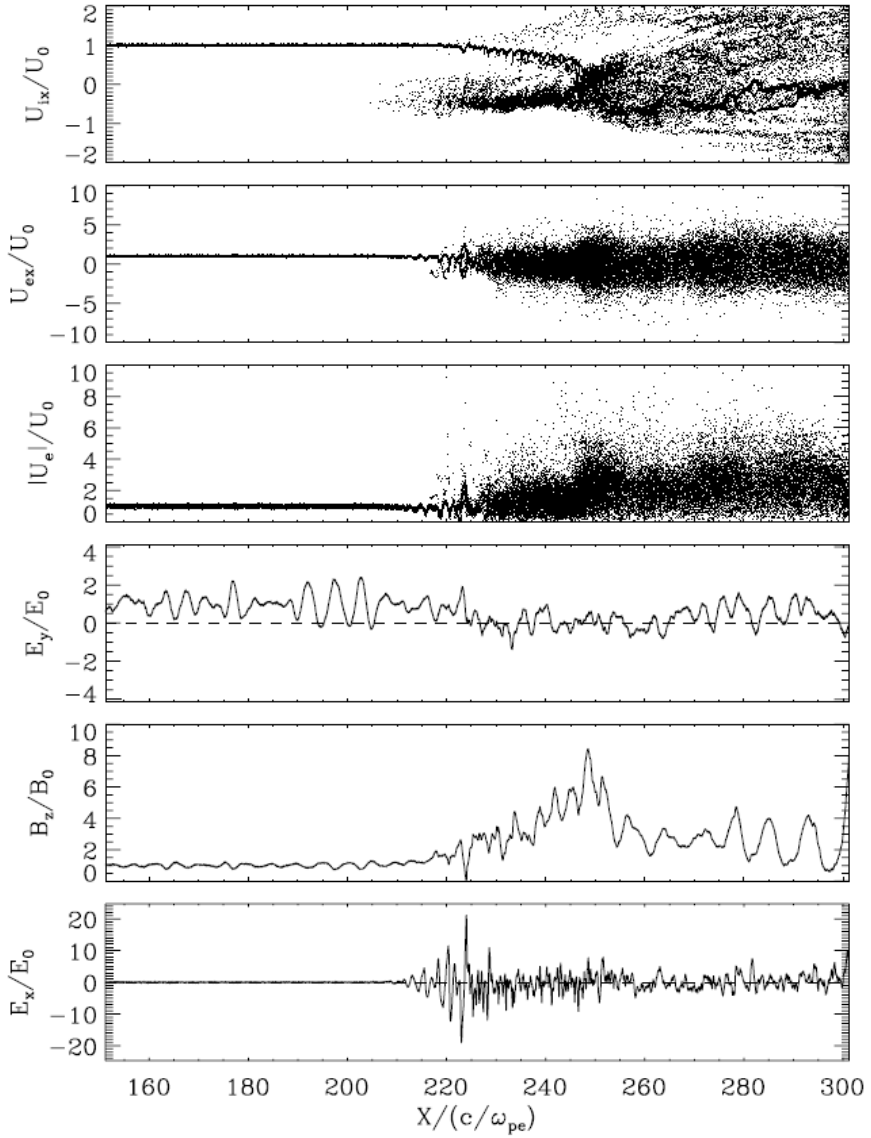
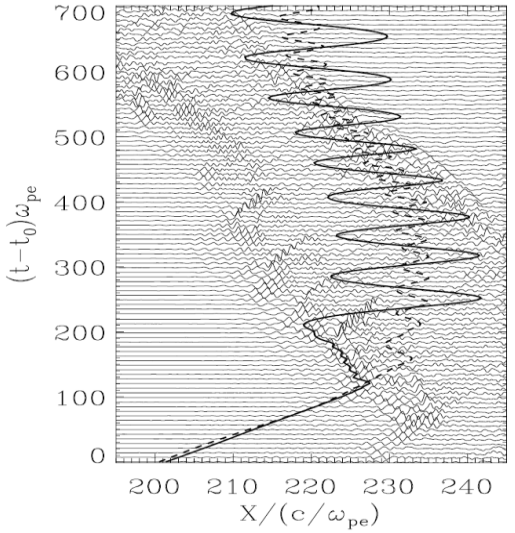
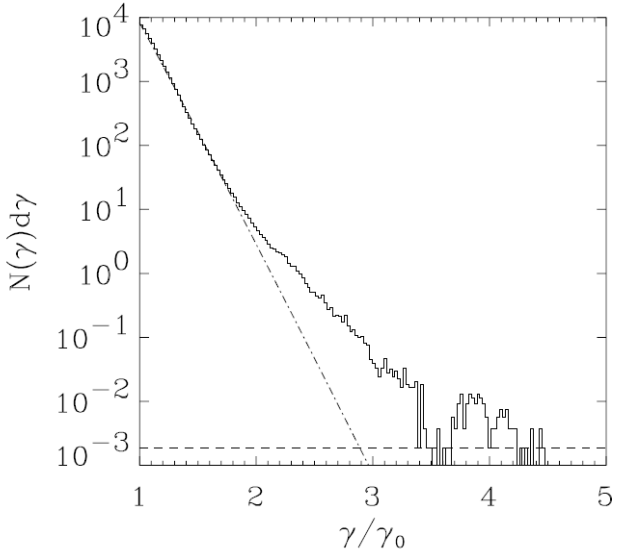


FIG. 1*a*

Hoshino+, ApJ, 2002

Electron holes and electron surfing acceleration in high Mach number shocks





selected crossings of the Earth's bow shock

#	date	time	**n**	θ_{Bn}	M_A	β_e	T_e/T_p
1	11092016	12:19:24	(0.91, 0.42, 0.01)	65.4	8.4	2.8	2.7
2	11042015	07:56:04	(0.98, 0.15, -0.11)	116	10.3	0.75	0.45
3	11042015	07:37:44	(1.00, 0.01, -0.04)	92.5	11.2	0.8	0.45
4	11022017	04:26:23	(0.76, 0.64, 0.11)	119	3.4	0.8	4.3
5	11022017	08:28:43	(0.85, 0.52, 0.10)	101	4.7	1.6	2.3
6	11302015	08:43:14	(0.99, -0.10, 0.12)	86	7	0.4	1.1
7	11092016	12:57:04	(0.93, 0.36, -0.01)	107	6.4	5.5	1.6
8	11022017	06:03:33	(0.80, 0.57, 0.18)	98	5.4	2.25	2.4
9	11042015	04:57:34	(0.99, 0.11, -0.01)	100	12.75	0.85	0.3
10	12282015	03:58:04	(0.96, -0.25, 0.10	101	24	3.3	3

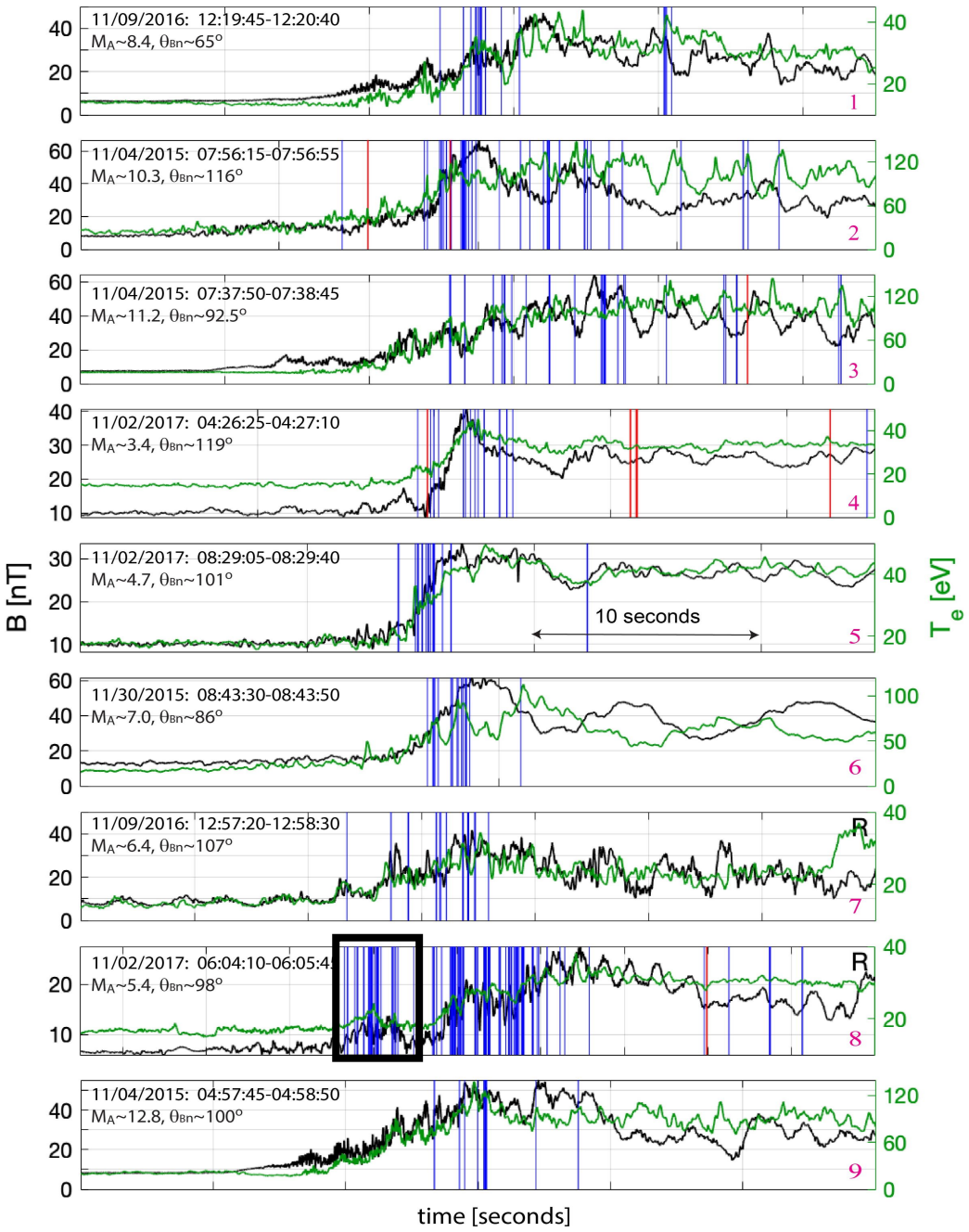
Vasko et al. (2020), *Frontiers in Physics*

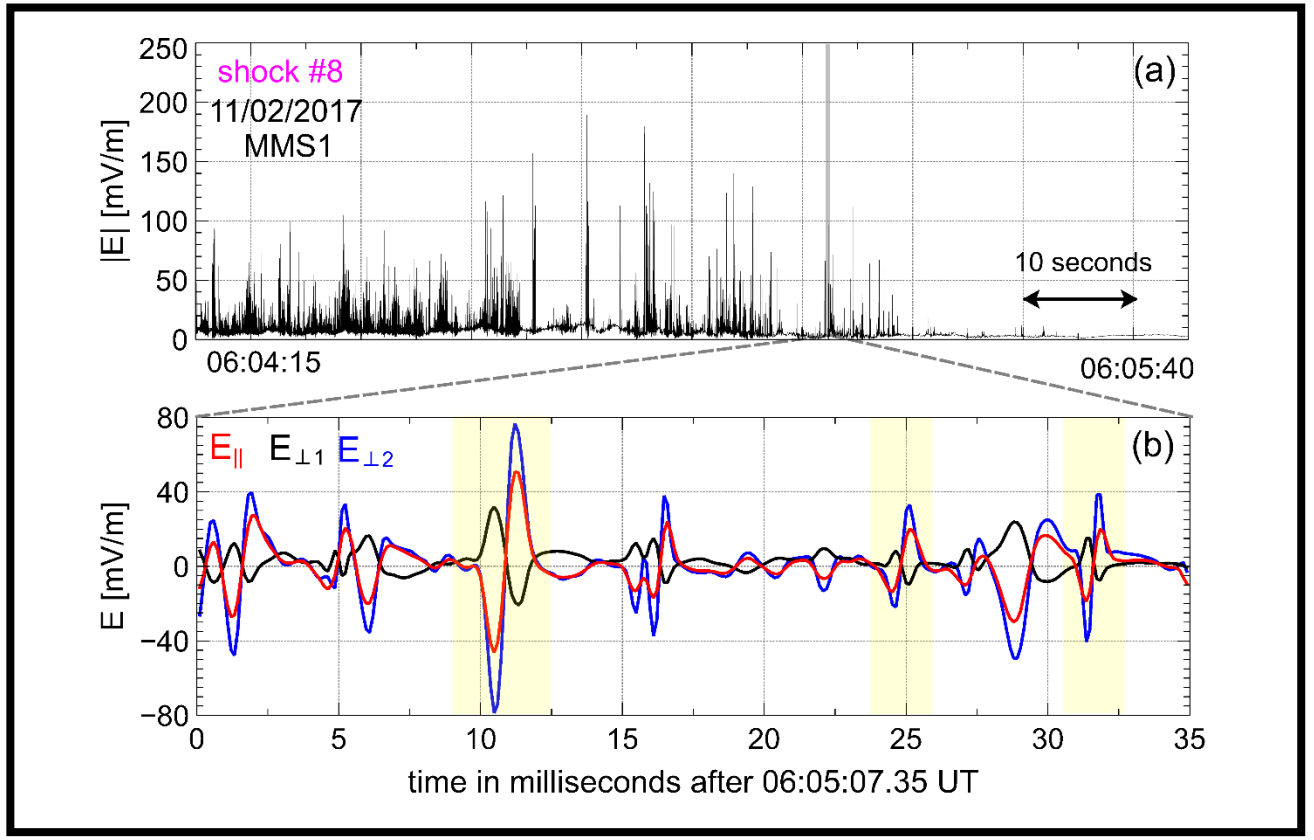
9 crossings of the Earth's bow shock and only bipolar solitary waves with amplitudes larger than 50 mV/m

Wang et al. in prep. for JGR

10 crossings of the Earth's bow shock and >2000 bipolar solitary waves with amplitudes as low as 10 mV/m

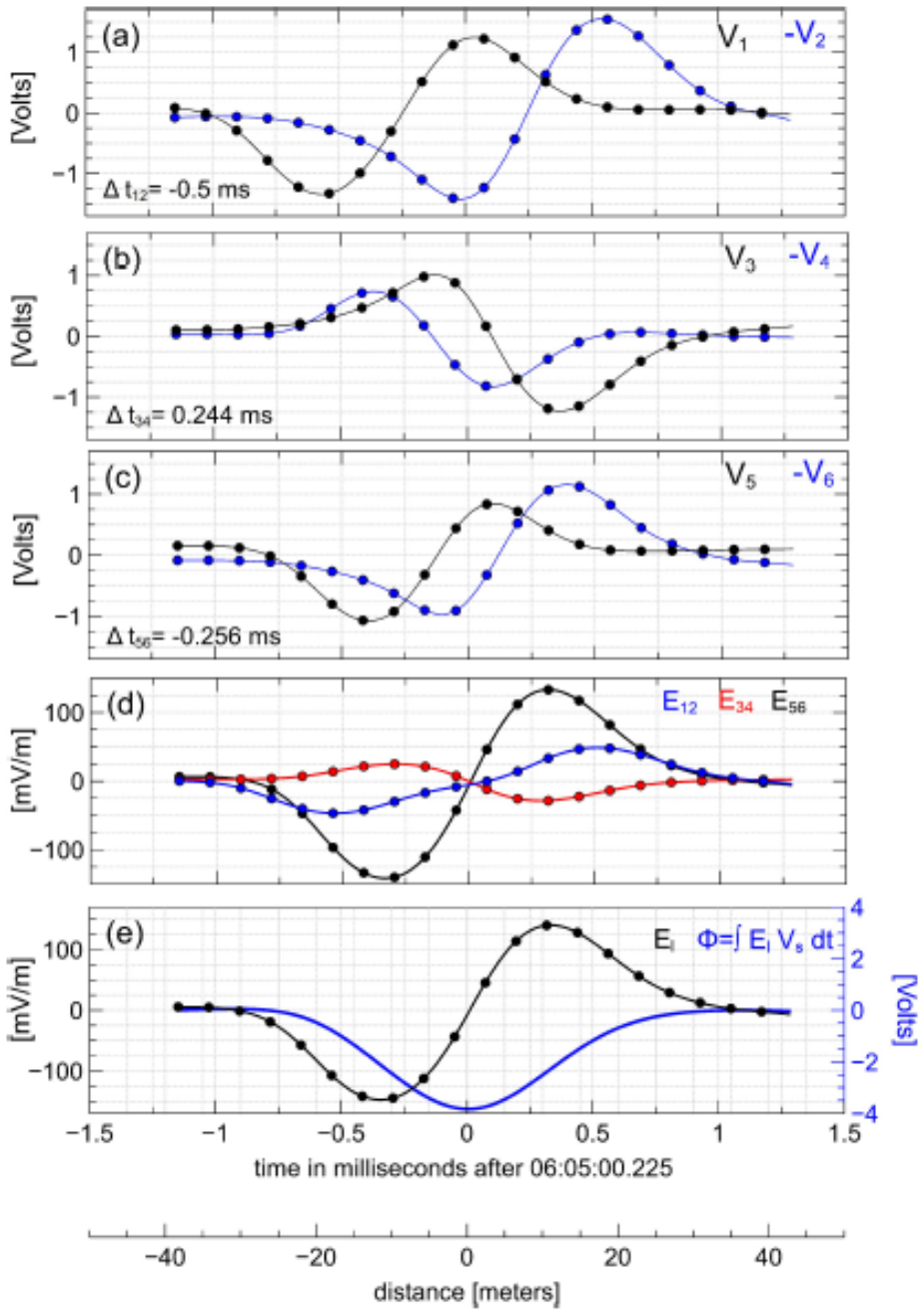
dataset of solitary waves





- 371 high amplitude (> 50 mV/m) structures from 9 MMS bow shock crossings
- Vertical lines indicate time of occurrence in each shock
- Colour reflects potential of ESWs (negative, positive)

Interferometry analysis



interferometry allows us to determine

wavevector **k**

speed $\mathbf{v_s}$

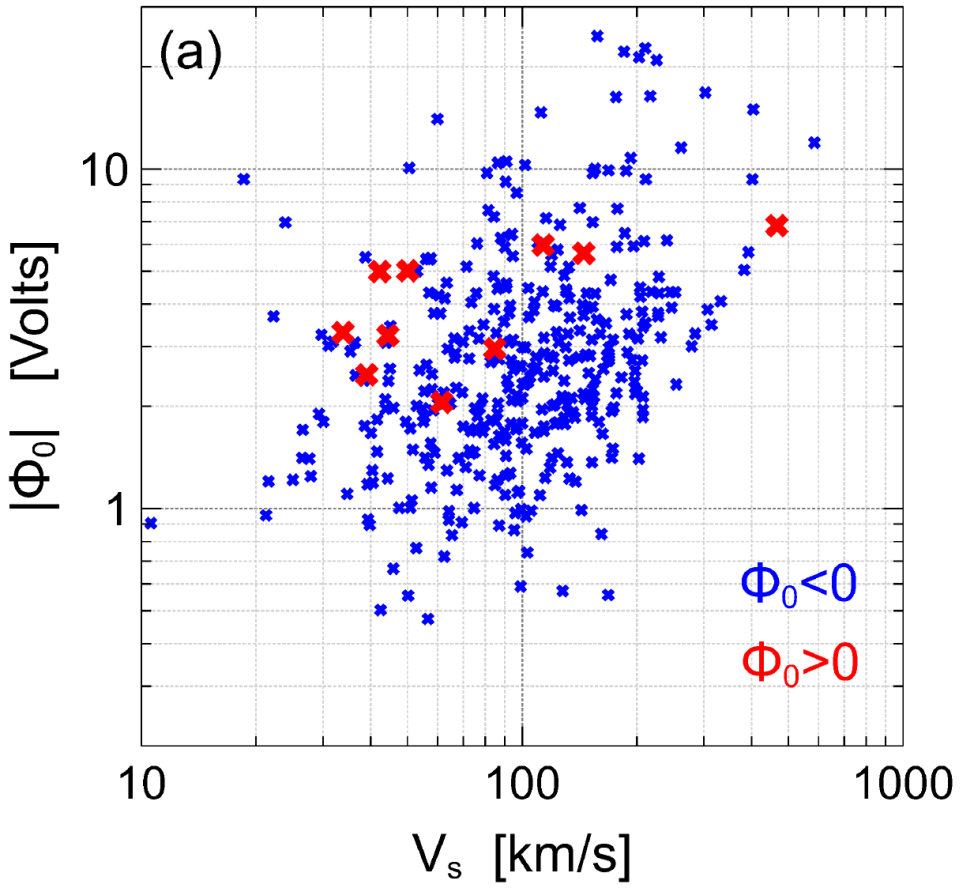
typical spatial width **l**

compute amplitude Φ_0 of electrostatic potential

electrostatic potential can be fitted to

$$\Phi = \Phi_0 \exp\left[-\frac{(\boldsymbol{kr} - v_s t)^2}{2\,l^2}\right]$$

nature of bipolar structures

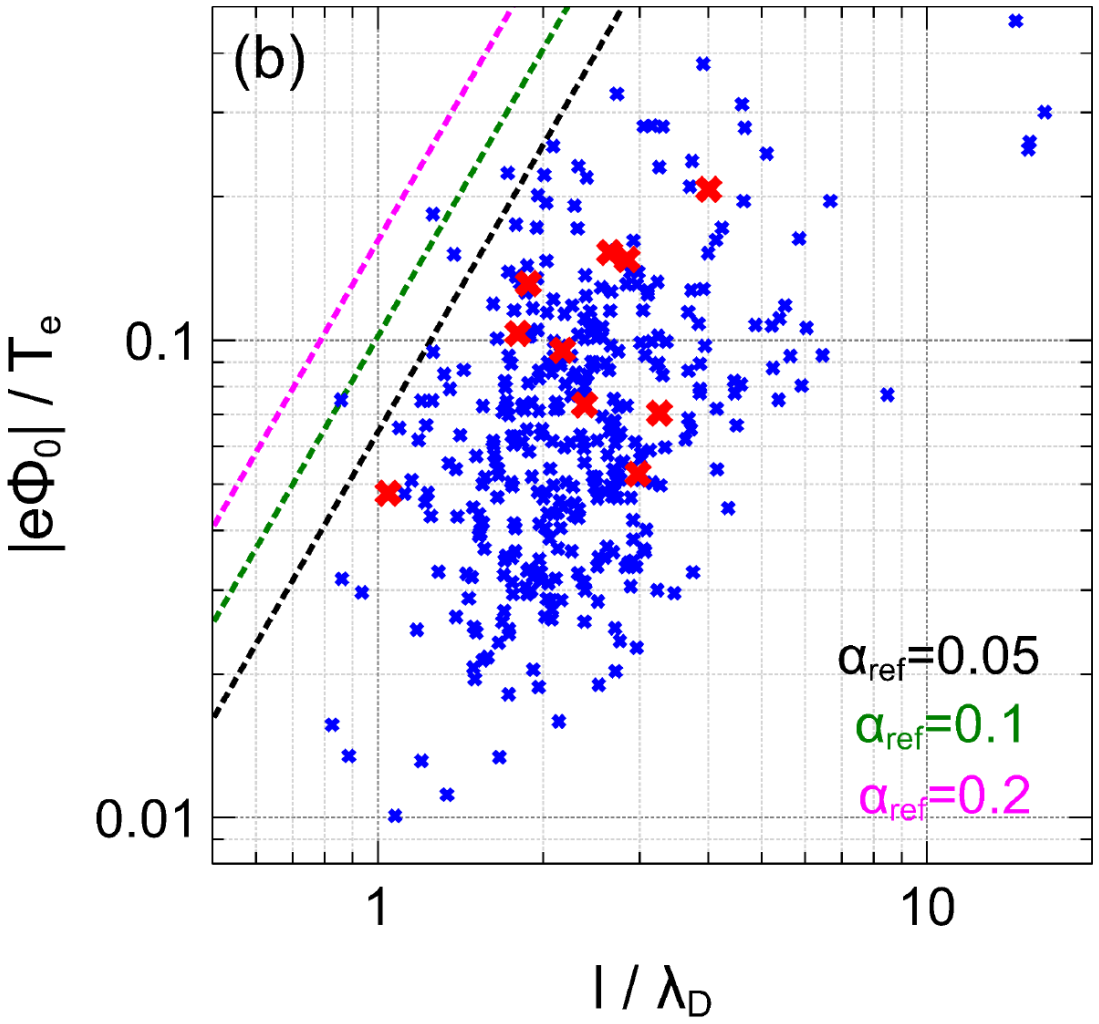


- solitary waves are predominantly ion phase space holes
- only 3% (10 out of 371) structures have positive potentials
- propagate with velocities of about 100 km/s in the SC frame (ion-acoustic type fluctuations)
- scarce amount of electron holes can be explained by the transverse instability. The stability criterion is

$$\omega_{be} < \omega_{ce} \quad \Rightarrow \quad \frac{e\Phi_0}{T_e} < \frac{l^2}{\lambda_D^2}\frac{\omega_{ce}^2}{\omega_{pe}^2}$$

- at realistic conditions $\omega_{pe}/\omega_{ce} \sim 100$ only very small amplitude electron holes (~0.01 V) can be stable for sufficiently long time

origin of bipolar structures



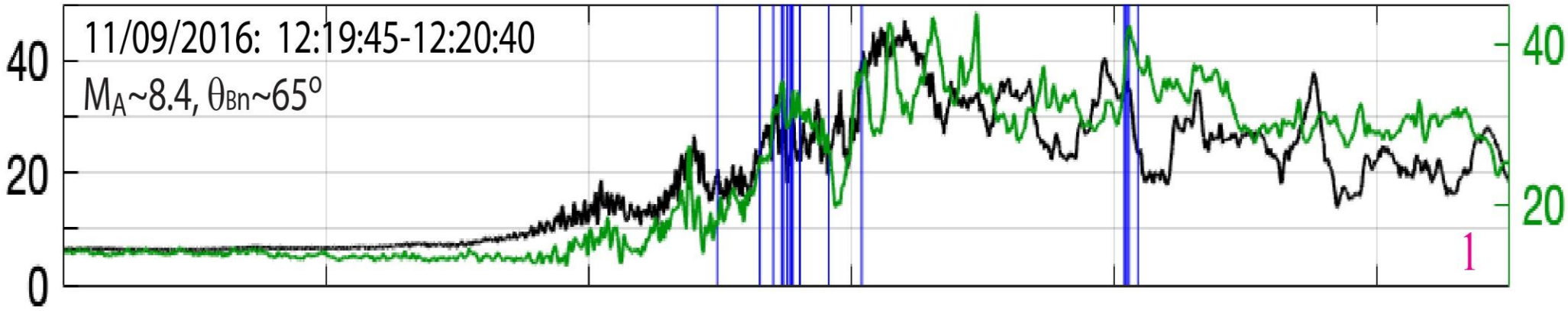
- Ion phase space holes are most likely produced by two stream ion instability. The condition for saturation of that kind of instability is

$$\omega_{bi} < \gamma \quad \Rightarrow \quad \frac{e\Phi_0}{T_e} < \left(\frac{\gamma}{\omega_{pi}}\right)^2 \frac{l^2}{\lambda_D^2}$$

maximum increment of a two-stream ion instability

$$\frac{\gamma}{\omega_{pi}} = \left(\frac{3\sqrt{3}\alpha_{ref}}{16}\right)^{1/3}$$

this is what occurrence of >50 mV/m bipolar structures looked like in shock#1



this is what occurrence of >10 mV/m bipolar structures looks like

(*Wang*+, in prep for JGR)