# Electrostatic fluctuations in the Earth's bow shock

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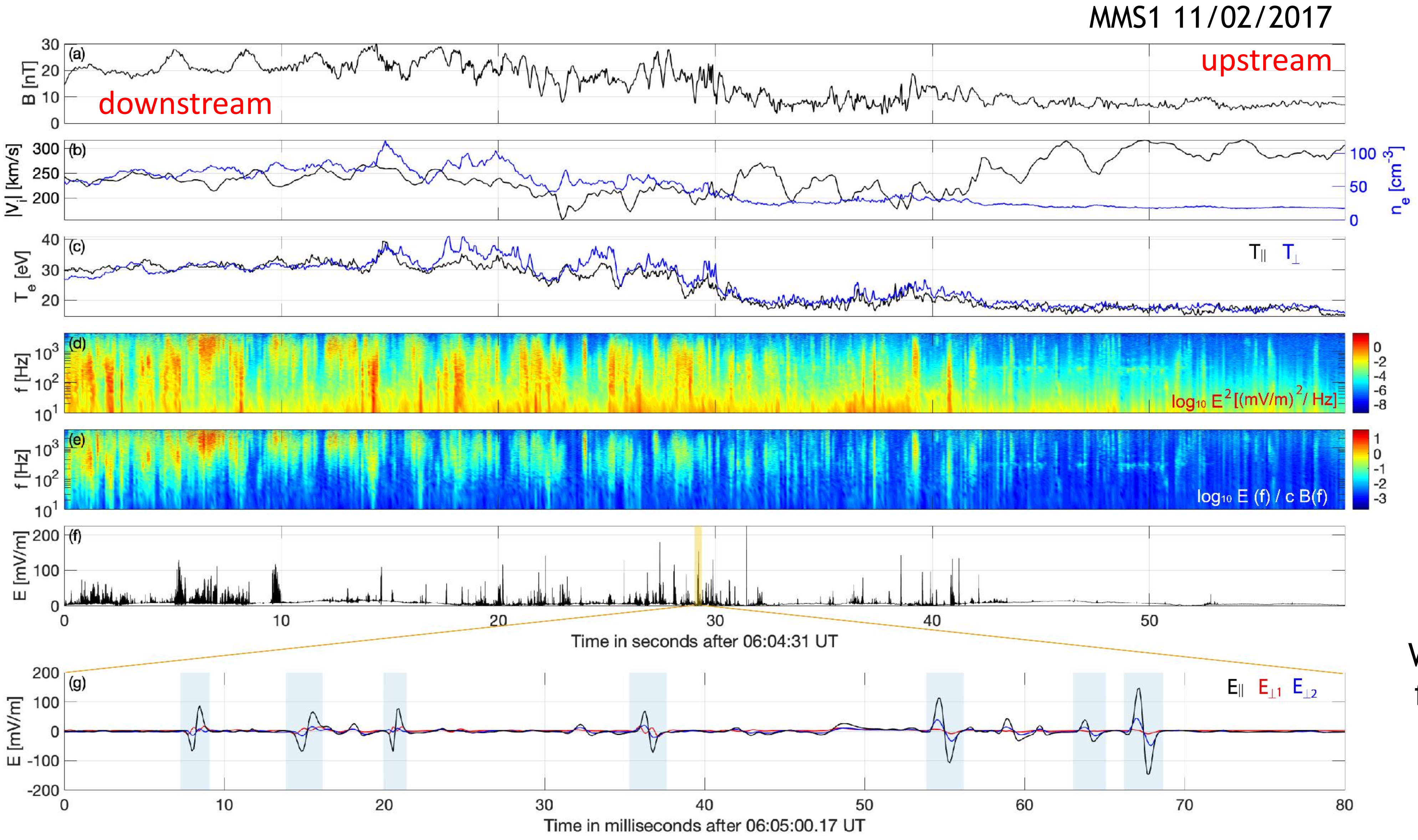
*Vasko*+ (2020), *Front. Phys.*, https://doi.org/10.3389/fphy.2020.00156
*Wang*+ (2020), *ApJL*, https://doi.org/10.3847/2041-8213/ab6582
*Wang*+ (submitted to JGR, arXiv:2103.05240)

# Broadband electrostatic fluctuations




*Wang+, apjl, 2020*

These fluctuations are always present in the Earth's bow shock

They consist of quasi-sinusoidal wave packets (IAW) and ESW

What instabilities drive electrostatic fluctuations in shocks?

What are effects of these fluctuations on electron thermalization?

<u>Selected crossings of the Earth's bow shock</u>

| # | date | time | **n** | $\theta_{Bn}$ | $M_A$ | $\beta_e$ | $T_e/T_p$ |
|---|---|---|---|---|---|---|---|
| 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+ (2020), Frontiers in Physics*

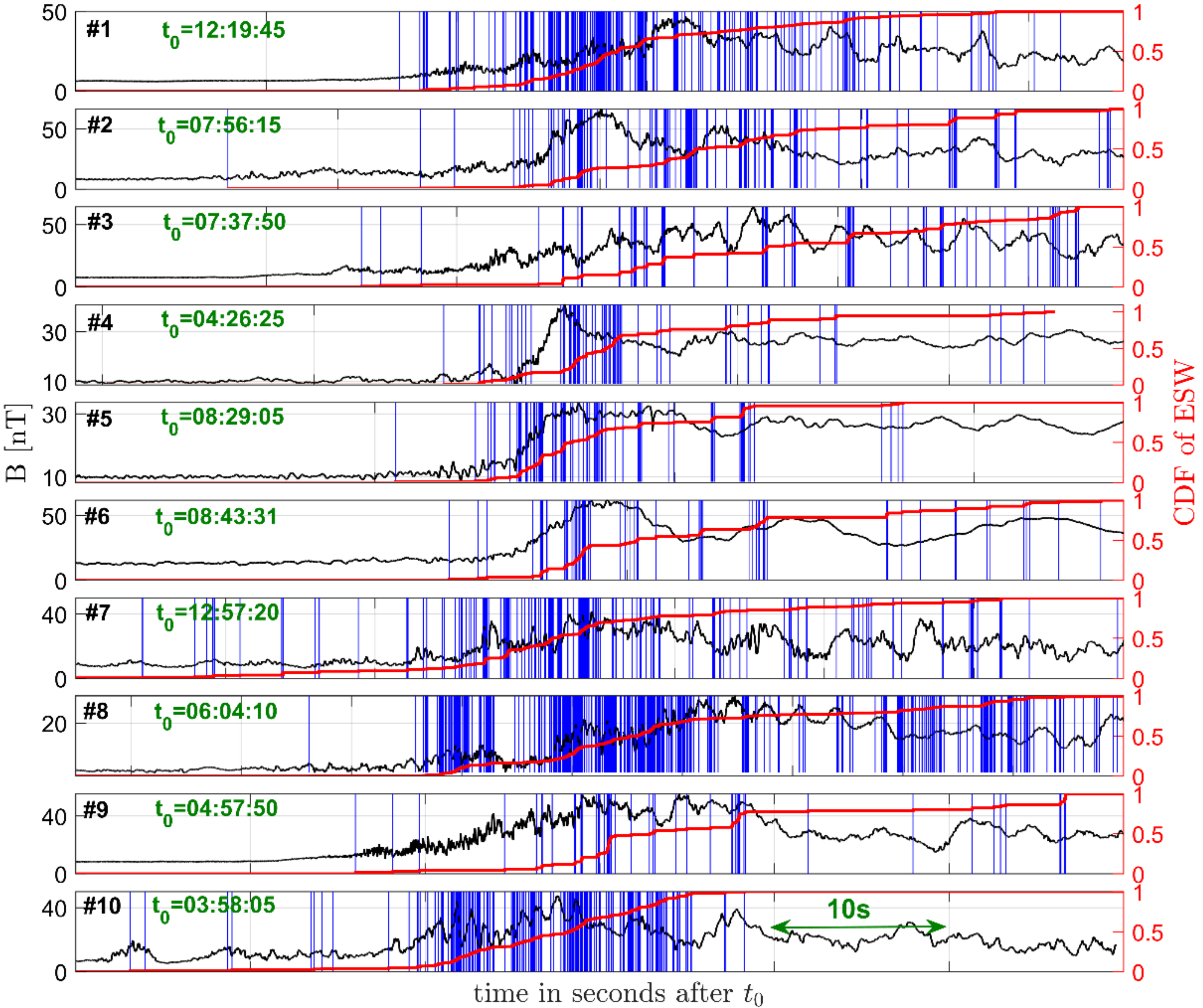
9 crossings of the Earth's bow shock and only bipolar solitary waves with amplitudes larger than 50 mV/m

*Wang+ (submitted to JGR)*

10 crossings of the Earth's bow shock and >2100 bipolar solitary waves with amplitudes as low as 10 mV/m

Additional motivation of this study: can we trust E56 and what is the optimal ratio of freq. resp. factors of axial and spin plane antennas?

# Dataset of electrostatic solitary waves (ESW)




- Vertical lines indicate time of occurrence in each shock
- Red curves give Cumulative Distribution Functions (CDF) of ESW number in each shock
- We could do interferometry for 1942 (our of 2136) ESW

101 (<5%) – positive potential structures (electron holes)

1841 (>95%) – negative potential structures (ion holes)

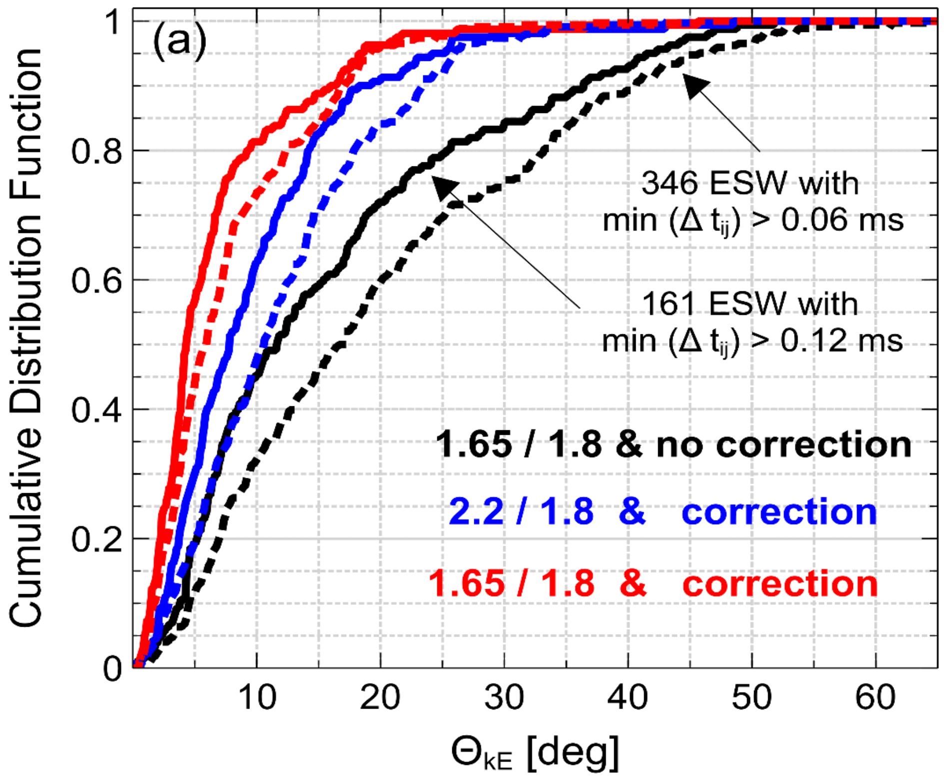
**Electrostatic fluctuations in the Earth's bow shock are predominantly produced by ion-streaming instabilities!**

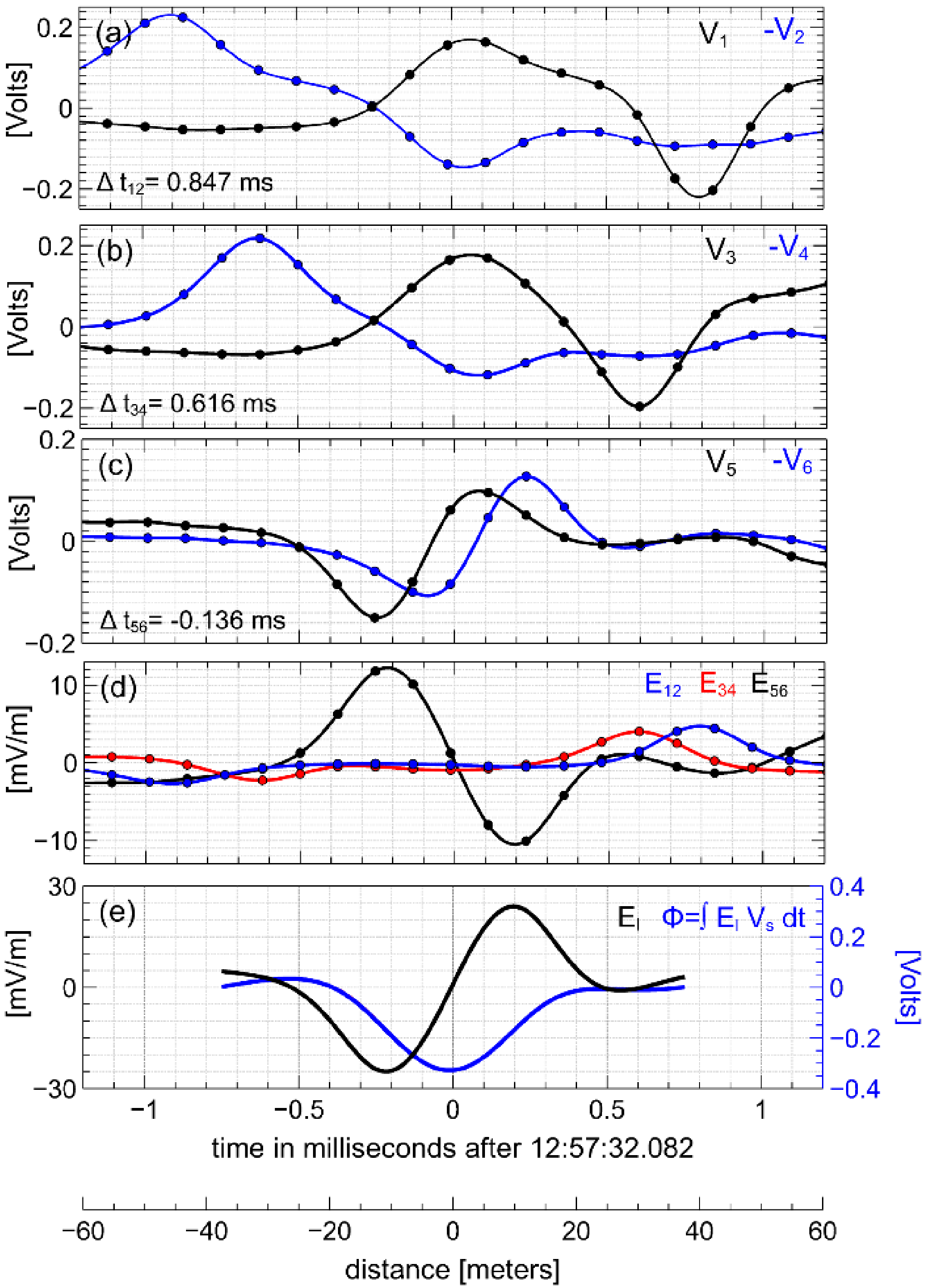
# Interferometry analysis and are we okay to use E56?

For 3 time delay events (~450 out of 1942) we could determine wave vector **k** using time delays and electric field **E** (effects of short scales were compensated)

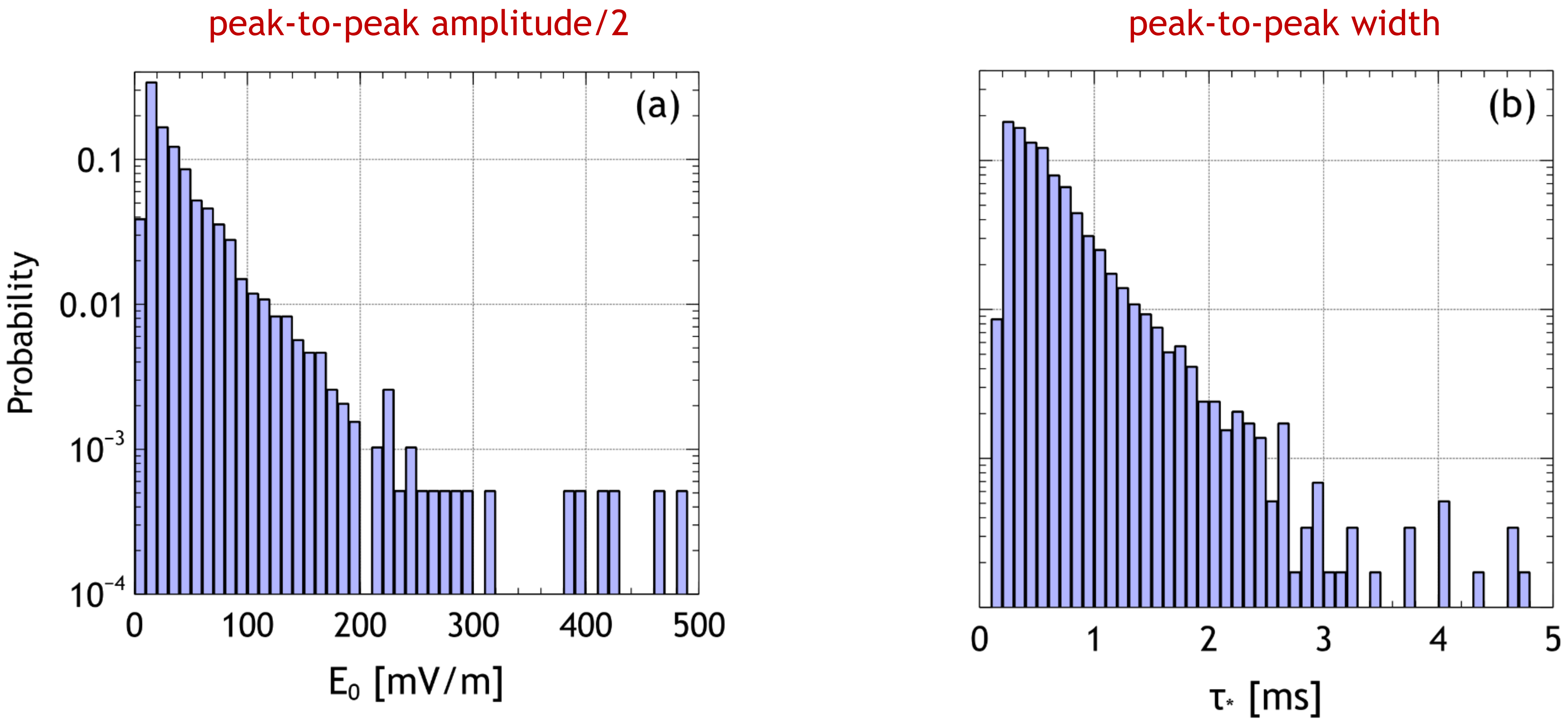
Agreement between **k** and **E** is an indicator of a good quality of measurements of electrostatic field

**Conclusion:** E56 is okay to use (correction to **E** has to be done; optimal freq. resp. factors ratio is around 1.65/1.8)



## Amplitudes and temporal widths of ESW

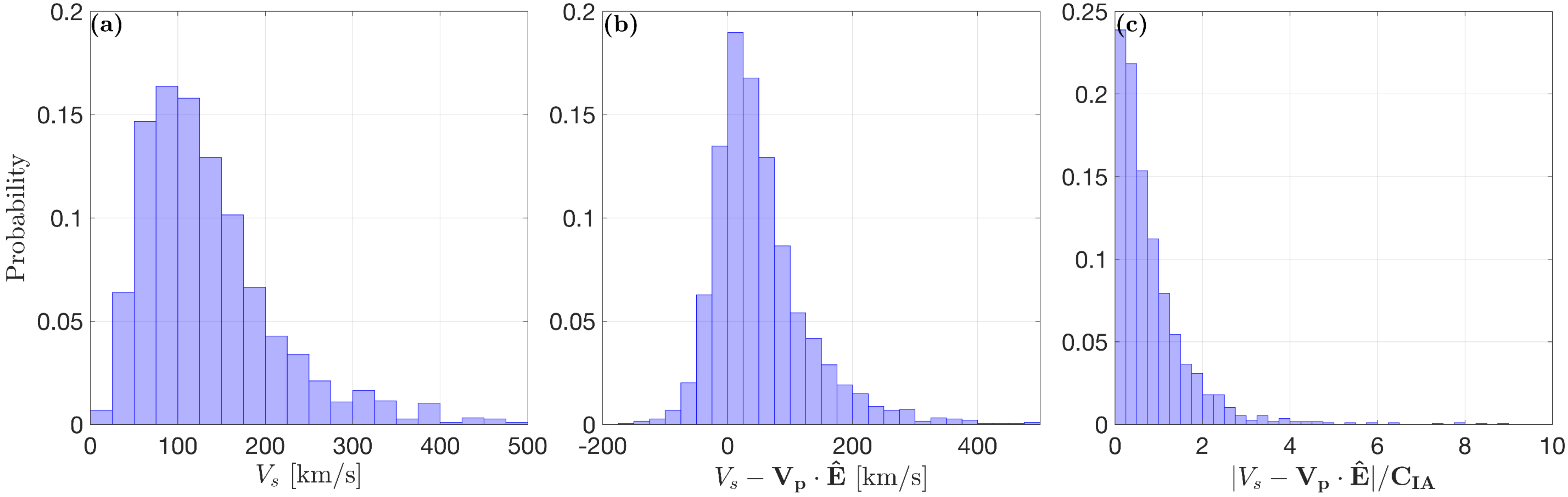


# Velocities of ESW

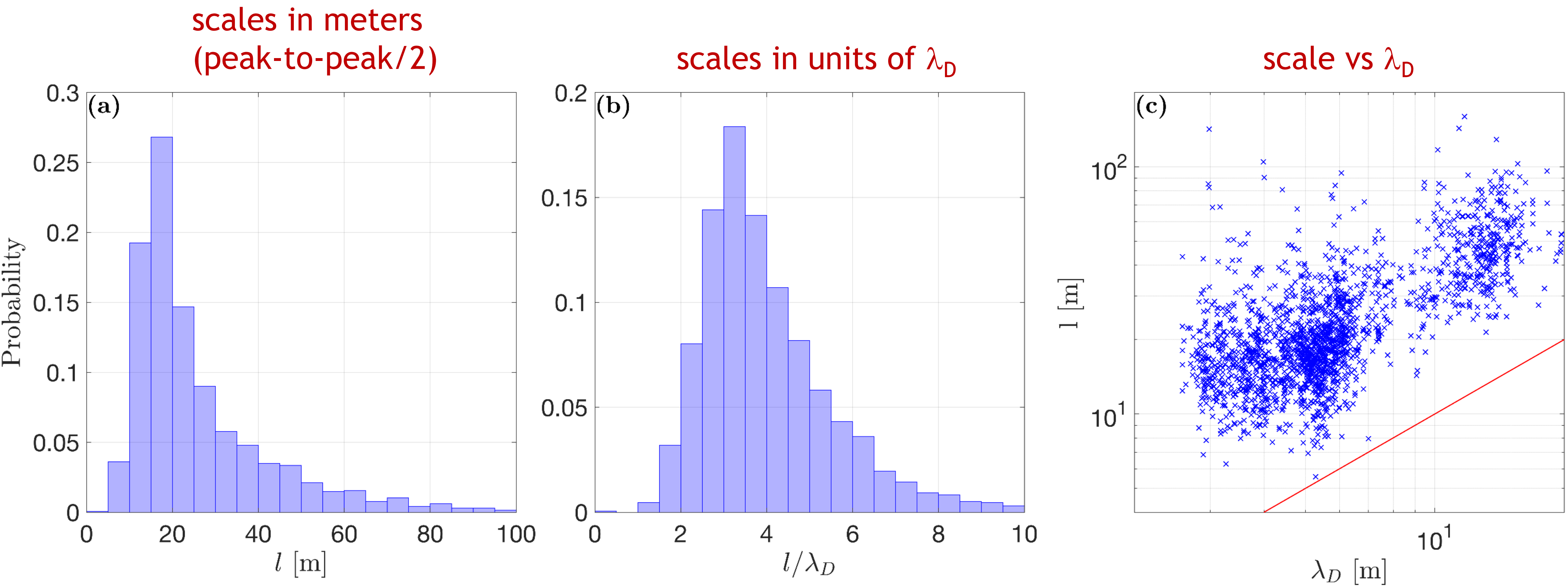
SC frame velocity

plasma frame velocity

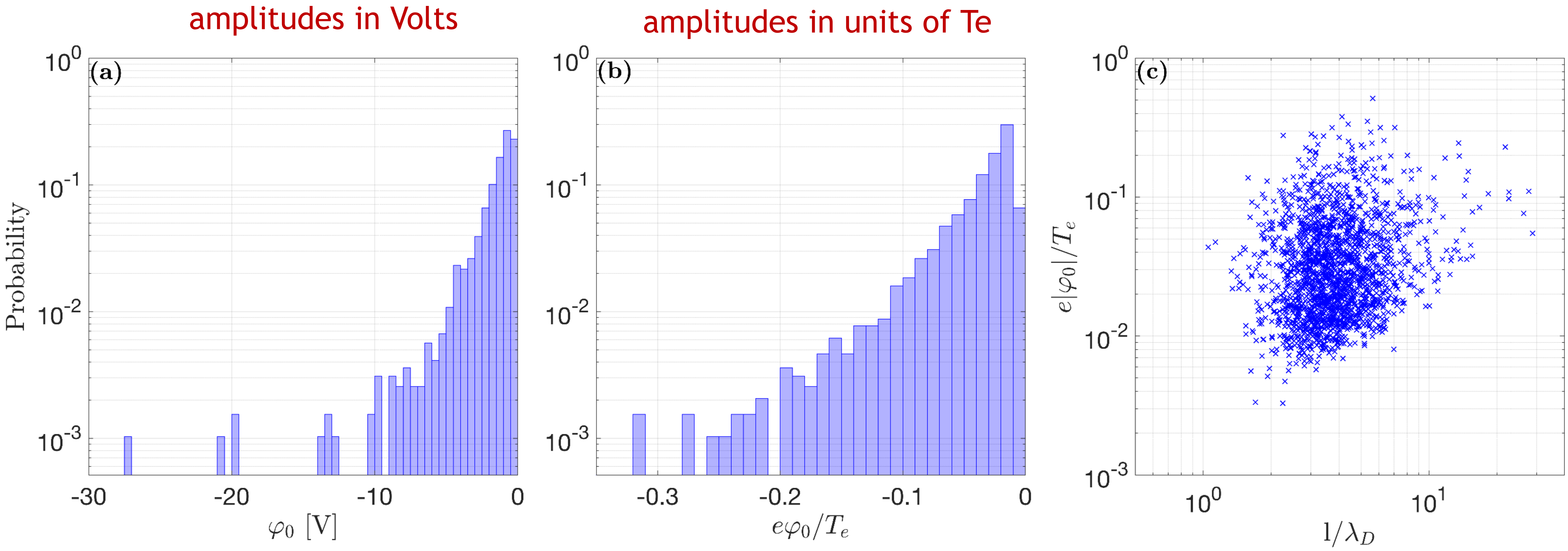
How it compares to ion-acoustic speed?



# Spatial scales of ESW



# Amplitudes of ESW

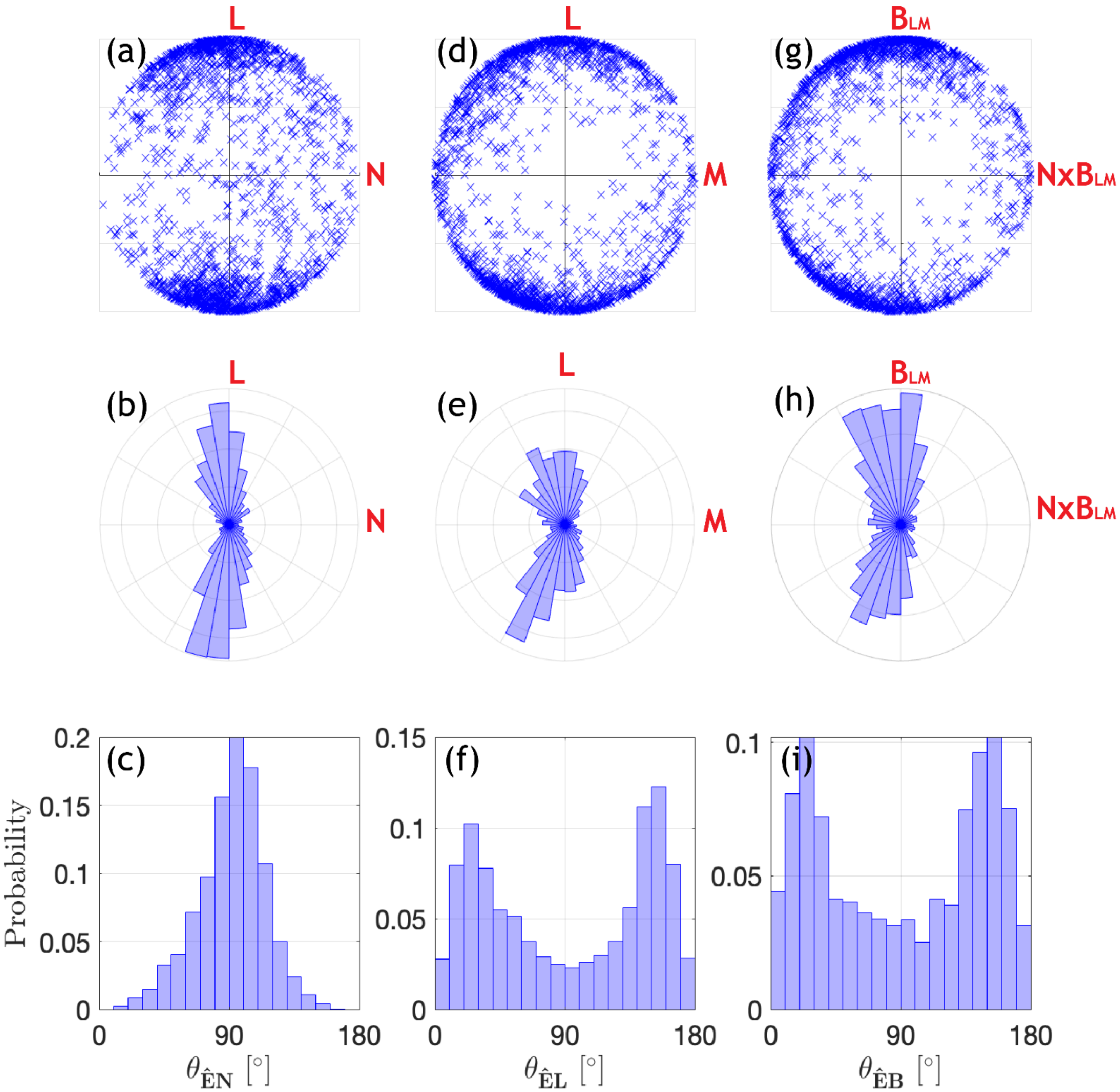


# Propagation direction (plasma rest frame)

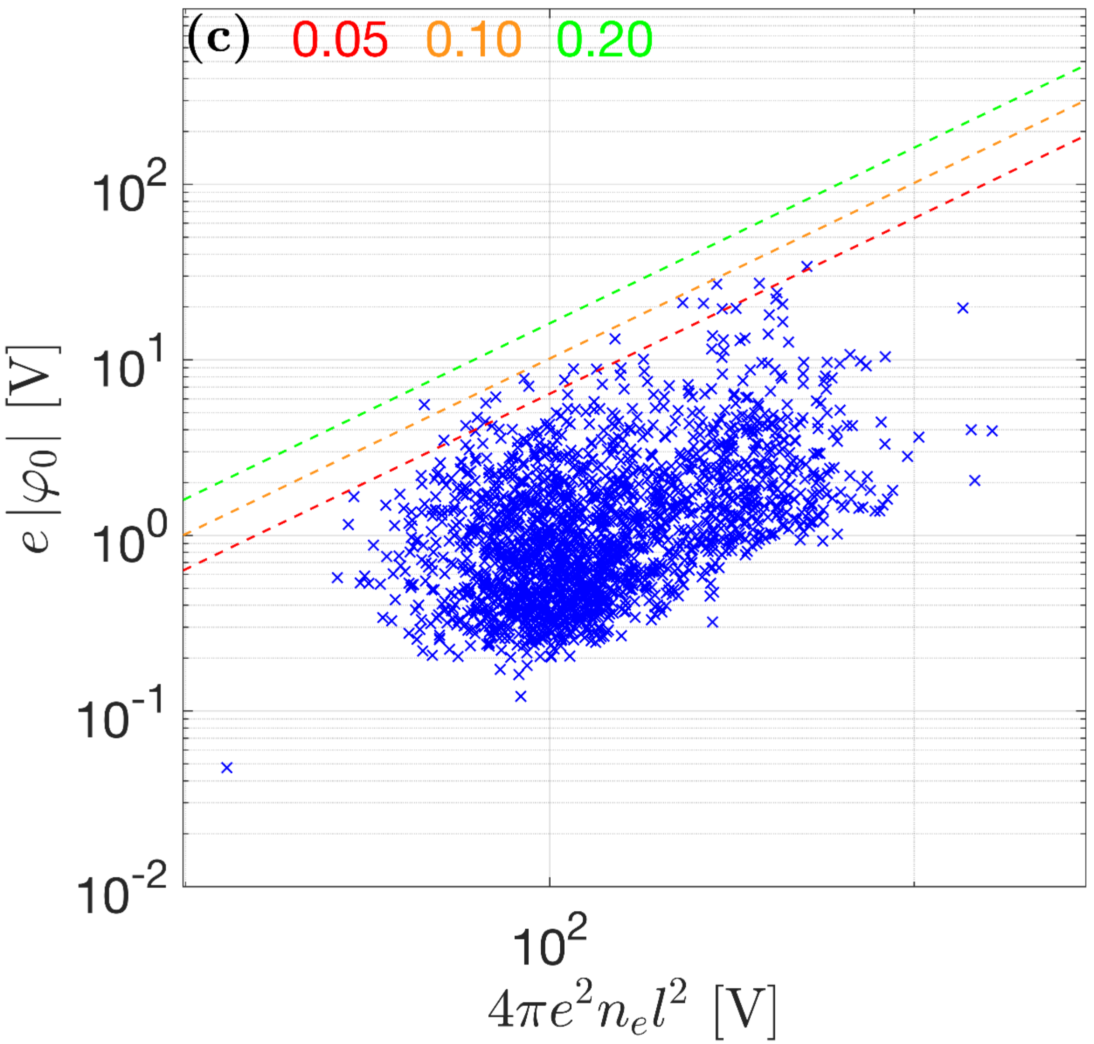
LM - the shock plane

LN - coplanarity plane

- ESW propagate within ~30° of the shock plane
- In the shock plane, they tend to propagate within 40° of $B_{LM}$ (about 25% of ESW have angle >45° though)
- In the shock plane, ESW prefer to propagate in the direction of $J_M$ current (as can be seen in panel (e) )
- In the plasma frame they can propagate toward both upstream and downstream (see panels (a) and (b))



# origin of bipolar structures




Ion phase space holes are most likely produced by ion-ion stream 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

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

This instability can also explain highly oblique propagation of ESW with respect to shock normal

# Conclusions

- 95% of electrostatic solitary waves in the Earth's bow shock are ion holes
- 5% of ESW are electron holes
- ESW have scales of 1-10 $\lambda_D$, speeds ~100 km/s that is ~$C_{IA}$, amplitudes of ~0.1Te. Scales are correlated with $\lambda_D$.
- ESW propagate within 30$^o$ of the shock plane and within about 40$^o$ of **B** projection onto the shock plane. 25% of ESW are very oblique to **B** (>45$^o$).
- In the plasma rest frame, ESW can propagate both toward upstream and downstream
- The most likely instability producing the observed ion holes is ion-ion streaming instability. It can explain the oblique propagation to shock normal, ion hole formation and observed amplitudes
- We could not find any particular dependence of wave properties on upstream parameters (Ma, $\beta$, $\theta_{BN}$)

The results of the ESW analysis show that electrostatic fluctuations in the Earth's bow shock should be predominantly produced by ion-streaming instabilities!