ON THE GENERATION OF ELECTROSTATIC SOITARY WAVES OBSERVED BY CLUSTER IN THE MAGNETOSHEATH

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Introduction

PRIOR TO 1997

- Earth's bow shock was explored through wave observations made by sweep frequency receivers and multi-channel analyzers (waveforms not available) or analog waveform receivers (difficult to extract waveforms for analysis).
- Various electromagnetic and electrostatic waves were observed upstream, in the shock transition region and downstream.
- Determining the mode of the electrostatic waves was difficult due to their broad, often featureless frequency extent.
- It was recognized that high time resolution digital waveforms were required to untangle the various modes.

AFTER 1997

Matsumoto et al. (*Adv. Space Res.*, 1997):

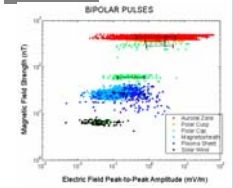
- Geotail PWI instrument waveform data (4 kHz bandwidth, 8.7 s snapshots every 5 minutes) show that several modes are present in the ac electric field measurements of the broadband electrostatic noise, one of the most surprising being the "Electrostatic Solitary Wave", or ESW.
- ESWs are in the form of bipolar pulses (one positive peak and one negative peak), have time durations on the order of 1-2 ms and peak-to-peak amplitudes of 60 mV/m in the bow shock transition region and 20 mV/m just downstream.

Bale et al. (*Geophys. Res. Lett.*, 1998):

- WIND WAVES TDS (120,000 samples/s, 17 ms snapshots) observes ESWs with time durations of ~ 0.1 ms and amplitudes > 200 mV/m in the shock transition region.
- Suggested that these ESW were Bernstein-Greene-Kruskal (BGK) modes in the form of electron phase space holes.

On to Cluster …

Figure 2



[From Pickett et al., *Ann. Geophys.*, 2004]

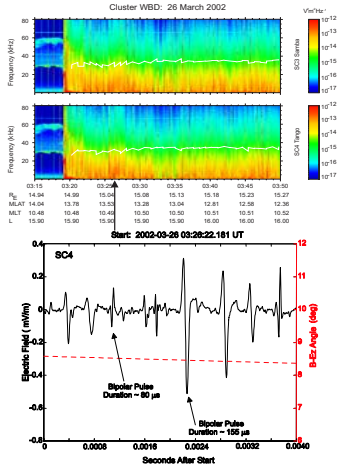
Conclusions:

Solitary waves (pulses) consistent with BGK mode.

Effect of finite magnetic field results in larger sizes and/or smaller potential amplitudes for smaller magnetic field.

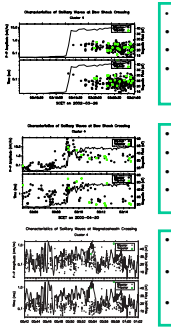
Governed by inequalities leading to an allowed range of amplitudes at any given field strength [From Chen et al., *PRE*, 2004].

Figure 1



Cluster WBD spectrogram (top two panels) showing spacecraft 3 and 4 as they transit from the upstream region of the quasi-perpendicular bow shock to the downstream magnetosheath region, with bow shock crossing at ~ 03:19 UT. The broad frequency bands observed in the spectrogram up to about 50-60 kHz are primarily the signature of the FFT rendering of numerous short duration solitary waves as observed in the bottom panel, which shows a 40 millisecond portion of the waveform used to create the spectrograms.

Figure 3

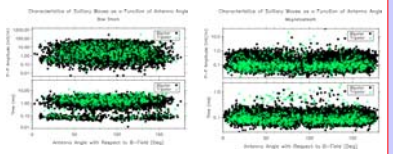


- Quasi-perpendicular, $\theta_{BN} \sim 85°$
- $\beta \sim 0.29$
- $M_A \sim 6.4$
- Almost total absence of ESWs in transition region, as well as upstream; numerous downstream, but very short time duration.

- Quasi-parallel, $\theta_{BN} \sim 33°$
- $\beta \sim 0.06$
- $M_A \sim 2.8$
- Many ESW detected at all locations near the bow shock; amplitudes greatest on the ramp

- Dayside Magnetosheath near Magnetopause at 11.5 R_E
- Most ESW time durations are less than 0.2 milliseconds with small amplitudes
- Cold (~ 39 eV) and hot (~ 79 eV) electron populations are present.

Figure 4



BOW SHOCK

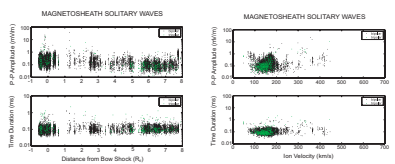
- Amplitudes as great as 100 mV/m P-P (WBD upper cutoff for most gain states)
- **Two distinct populations:** 1) time duration < 0.2 ms (order of electron plasma period) at angles other than 90º and 2) time duration > 0.2 ms at all angles

MAGNETOSHEATH

- Amplitudes usually no greater than 1 mV/m P-P
- **One distinct population:** time duration < 0.2 ms at angles other than 90º, order of electron plasma period

Figure 6

[From Pickett et al., *Nonlinear Proc. in Geophys.*, 2005]



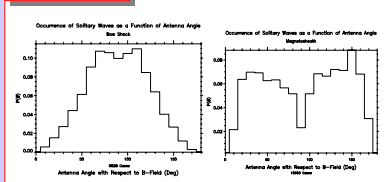
Distance from Bow Shock

- No dependence for amplitude or time duration
- Suggests local generation at multiple locations in the magnetosheath rather than generation at bow shock

Dependence on Ion Velocity

- Slight trend for larger amplitudes at larger velocities, but no dependence for time duration
- Suggests ions not solely responsible for creation

Figure 5



BOW SHOCK

- Angle occurrence peaks around 90º
- Suggests that ESWs do not propagate along the magnetic field

MAGNETOSHEATH

- Angle occurrence nearly equal at all angles except 90º
- Suggests that ESWs primarily propagate along the magnetic field

GENERATION MECHANISM

- Observationally, it is hard, if not impossible, to determine the generation mechanism of the solitary waves in the magnetosheath and around the bow shock since particle measurements are made at much lower time resolution than the waveform measurements.
- Three likely possibilities:
  - Beam instability such as the counterstreaming instability, which has possibilities in the magnetosheath since counterstreaming electrons are observed during major ESW events. These would be BGK mode.
  - Spontaneous generation out of turbulence since ESW are observed most abundantly in turbulent regions and a significant amount of turbulence is observed in most magnetosheath crossings. These too would be BGK mode.
  - Acoustic mode (electron or ion), which in the case of electron acoustic mode would require a cold and hot population as well as an ion population, which might be possible in the magnetosheath and solar wind. These would be fluid solitons.
- We need to look at numerous ESW events across the bow shock and magnetosheath and the particle populations that are observed during them to find statistical correlations and trends.

SUMMARY

- Electrostatic solitary waves (solitary structures) are observed in the solar wind, across the bow shock and in the magnetosheath.
- These ESW have time durations consistent with electron modes (< 100 microseconds or less) and ion modes (> 200 microseconds) and amplitudes which, for the most part, are consistent with BGK modes.
- If BGK mode, the bipolar ESW would imply trapping of one of electrons or ions, whereas the tripolar ESW would imply trapping of both.

FUTURE WORK

- Compile a larger statistical base of bow shock and magnetosheath crossings using the Cluster WBD 77 and 9.5 kHz bandwidth filters.
- Explore the various generation mechanisms from a theoretical perspective using observed particle and field inputs to models.

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