Observations of Electrostatic Solitary Waves as Evidence of Instabilities and Magnetic Reconnection at Solar Wind Current Sheets

David M. Malaspina¹, David L. Newman², Lynn B. Wilson III³, Keith Goetz⁴, Paul J. Kellogg⁵, Kris Kersten⁶

1. Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, CO, USA.
2. Center for Integrated Plasma Studies, University of Colorado, Boulder CO, USA
3. NASA Goddard Spaceflight Center, Greenbelt, MD, USA
4. School of Physics and Astronomy, University of Minnesota, Minneapolis, MN, USA

Abstract

Using data from the Wind spacecraft, we present observations of a strong spatial association between bipolar electrostatic solitary waves (ESW) and magnetic discontinuities (current sheets) in the solar wind. This association implies that the plasma instabilities (e.g., Buneman, electron two-stream) responsible for creating ESW are both active in the solar wind and localized to current sheets.

The presence of these instabilities suggests the transfer of magnetic energy to electrostatic waves at solar wind current sheets either through the saturation of current-driven instabilities or through magnetic reconnection.

Current sheet properties are compared between current sheets associated with ESW and randomly chosen current sheets. No significant difference is found between these two populations with respect to thickness, or vector magnetic field change, implying that the generation of ESW at current sheets occurs throughout the solar wind at 1 AU. Of the possible mechanisms considered for producing ESW-generating instabilities at solar wind current sheets, we argue that magnetic reconnection is the most likely.

Electrostatic Solitary Waves (ESW)

Electrostatic, short duration pulses often indicating non-linear Debye-scale potential structures, often produced by electron and/or ion streaming instabilities

Electrostatic Debye-scale structures, with:
- + bipolar E-field along B
- + unipolar E-field perpendicular to B
- + streaming electron
- -
- -

Instabilities I

1) ESWs in the solar wind are identified as e phase space holes.
2) Magnetic discontinuities are observed preferentially near ESWs in the solar wind, indicating active streaming instabilities associated with these current sheets.
3) Magnetic reconnection is the most likely source of streaming instabilities at these current sheets, based on simulation results and observed current sheet properties.
4) Too little current is available to drive the Buneman instability from B-shear alone, unless current sheets have fine scale magnetic structure or density cavities.
5) Observations of ESWs indicate that instabilities localized to current sheets are actively transferring magnetic free energy to electrostatic wave energy in the solar wind at 1 AU.

Conclusions

Current Sheets as a Source of ESWs

Compare two sets of current sheets:
1) Current sheets nearest to Wind when ESWs are observed (4,393) during 2007 (Black curves)
2) Current sheets nearest to Wind at randomly selected times (4,113) during 2007 (Red curves)

Current sheets are far more likely than random chance to be observed close to ESWs

Current sheets are found within 6,000 km for 47% of ESW observation locations, but for only 17% of randomly selected locations

Current Sheet Identification

Magnetic discontinuities (current sheets) identified in 92 ms Wind MAG data using:

Partial Variance of Increments (PVI) method [Greco et al. 2008]
- Selects strongly non-Gaussian fluctuations
1) Calculate PVI for 130 scale sizes (di) between 92 ms and 12 sec
2) Retain points where PVI > 5
3) For each ‘island’ of PVI values > 5, find the location of max PVI over all scales
4) The scale (di) associated with PVI max gives the width of the current sheet

Current Sheet Properties

- Current sheets nearest ESW observation locations (black)
- Current sheets nearest randomly chosen locations (red)

Similar B-field change

Similar current sheets nearest ESW observation locations (black)

Probability of finding a current sheet near an ESW is greater than random in the slow solar wind, less than random in the fast solar wind

ESW as e Phase Space Holes

Monopolar structures perp. to B look tripoal due to AC coupling of Wind E-field measurement

(A) and (B) show 2 ms and 8 ms bipolar pulses (black)
Bipolar pulses with power < 120 Hz removed (red)
(C) and (D) show same for unipolar pulses
Potential structure velocities ≥ v₁ typically therefore ≥ 0.3 vₑ (electron thermal speed)

ESW bipolar axes always oriented closer to B than vₑ (examining 363 ESW where B = 5° from the Wind spin plane)
Observed ESWs are typically a few 10's of Debye lengths

ESW as e Phase Space Holes

4,393 ESW total during 2007 on Wind

0.015 km

X-axis: Distance from Wind to nearest current sheet

ESW amplitude (peak-to-peak) decreases with distance away from current sheets

Wind observes: e holes temporally associated with magnetic current sheets in the solar wind

e holes are excited by streaming instabilities: Buneman, bump-on-tail, e two-stream

Processes known to drive these instabilities and produce e holes:

Reconnection: laboratory [Fox et al. 2012], magnetopause [Matsumoto et al. 2003]
e beams: bow shock [Bale et al. 2008], IP shocks [Williams et al. 2005],
- cusp [Pickett et al. 2001], laboratory [Lefebvre et al. 2010]
- double layers: aurora [Ergun et al. 1998], magnetotail [Pickett et al. 2009]