Nonlinear Interaction of the Solar Wind with Earth's Bow Shock

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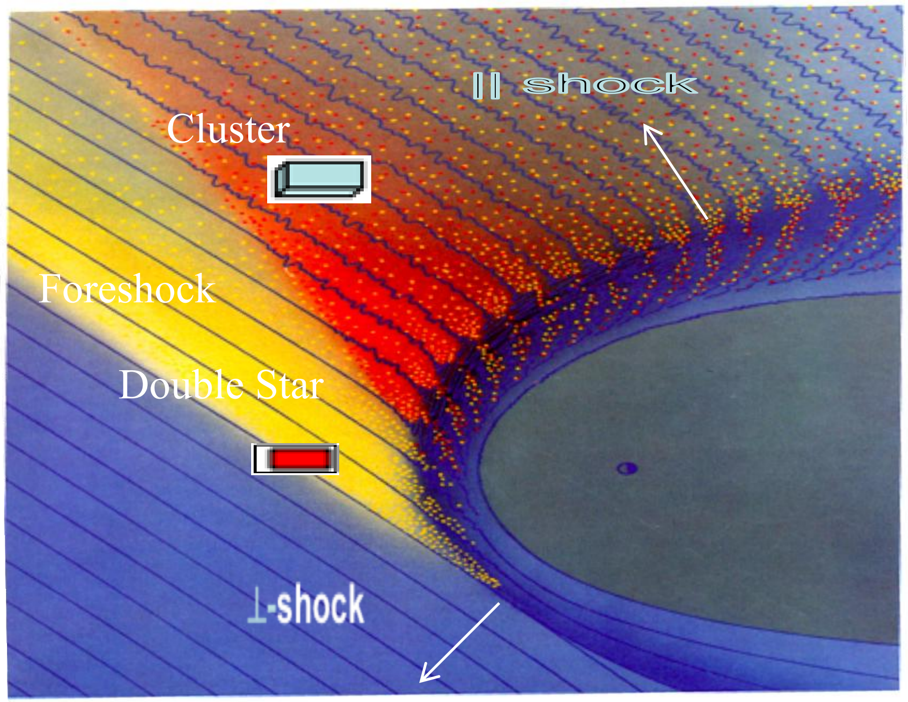
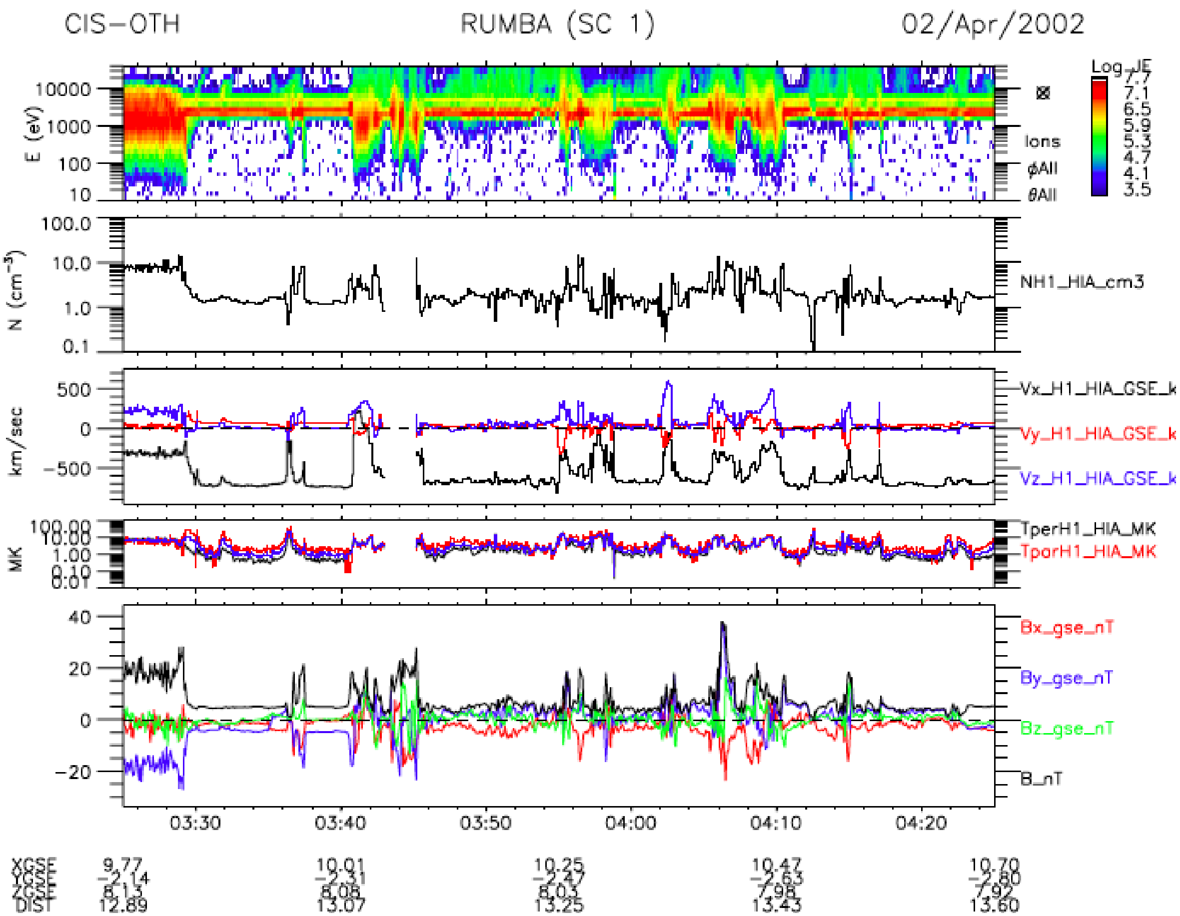
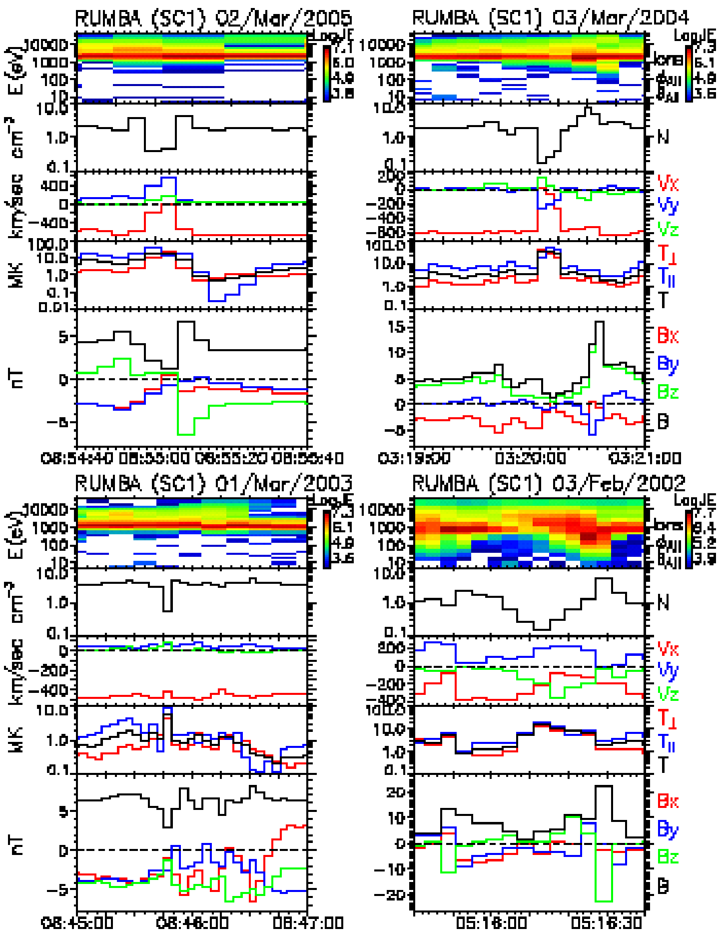


Nonlinear structures upstream of Earth's bow shock



Nonlinear Structures are *spikes in density* seen upstream of the bow shock.

HFA (Schwartz, 1985)
HDC (Thomsen, 1986)
SLAMS (Schwartz, 1992)
FC (Sibeck, 2002)
DH (Parks, 2006)



Properties Common to Upstream nonlinear structures

Cluster Observations:

- *δn/n* as large as 0.98
- *Duration* >4s
- ***Edges overshoot***, ~2-6 times
- ***Slowdown of SW***: Vx ~0, Vy, Vz deviated.
- ***T increases*** inside ($T>10^{7}$ °K)
- ***B changes sign*** (Current Sheet)
- *B-field* Similar shape as particles
- *Backstreaming population* always seen.

Random sampling of 147 DHs in five bow shock crossings.

2002, ULF waves made a θ_{BN} determination problematic, yielding a rough estimate ~30° (45°).

A sample of 147 holes observed during six orbits were used for a preliminary characterization. These results shown in Fig. 3 indicate density holes have a mean duration of 17.9±10.4 s and a mean $\delta n/n$ of 0.69±0.15. The δn repre-

- Mean duration Δt ~17.8 ± 10.4s
- fractional density depletion $\delta n/n$ ~.69 ± 0.15
- magntic field rotation ~36° ± 24°.

- DHs have many similar features as in HFAs, except they have *shorter duration* and *occur more frequently.*

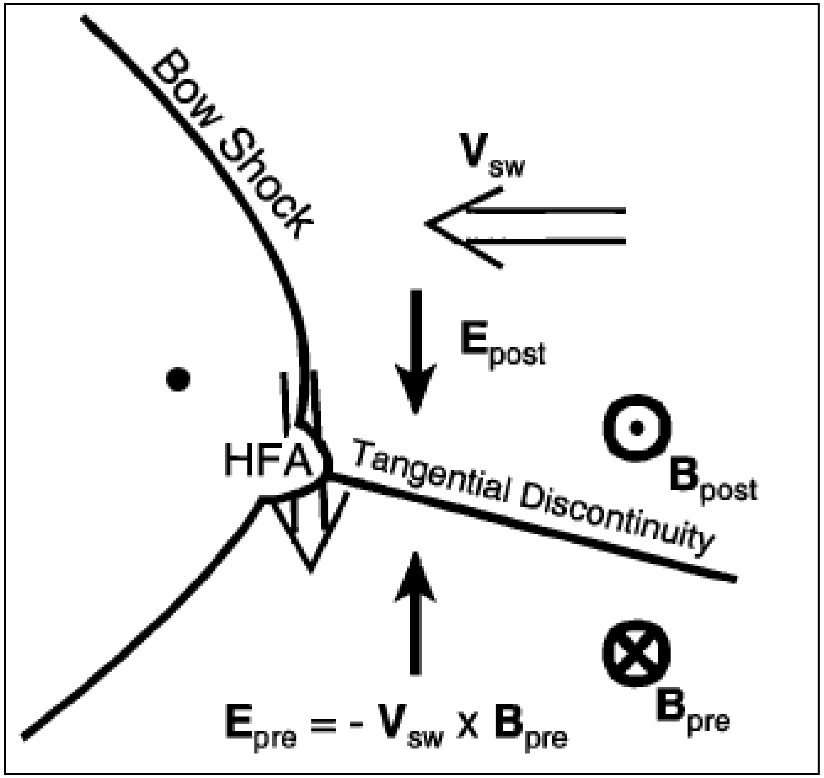
- This talk focuses on the relationship of DHs to HFAs.

  - What relationship, if any, do DHs have to the well-studied HFAs?

  - Could DHs be, for example, early stage HFAs that fail to fully develop for some reason?

  - Can we identify the physical basis for identifying DHs and HFAs?

Burgess and Schwartz (1988)



- SW E-field point inward *normal* to CS

- HFA produced by *IMF current sheet* interacting with the bow shock.
- IMF CS is connected to the bow shock.
- Reflected SW channeled into the CS, *Increases Temperature*
- CS *expands*, Compresses and steepens the edges into *shocks*.

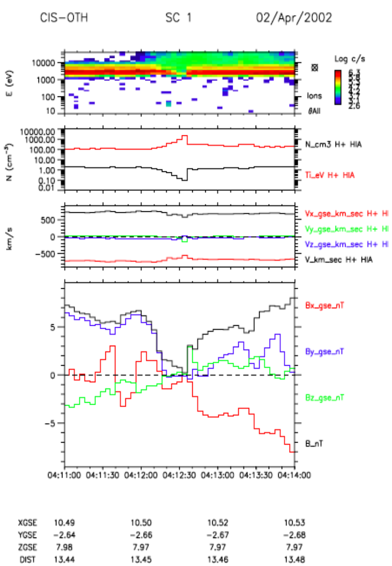
HFA Tests:

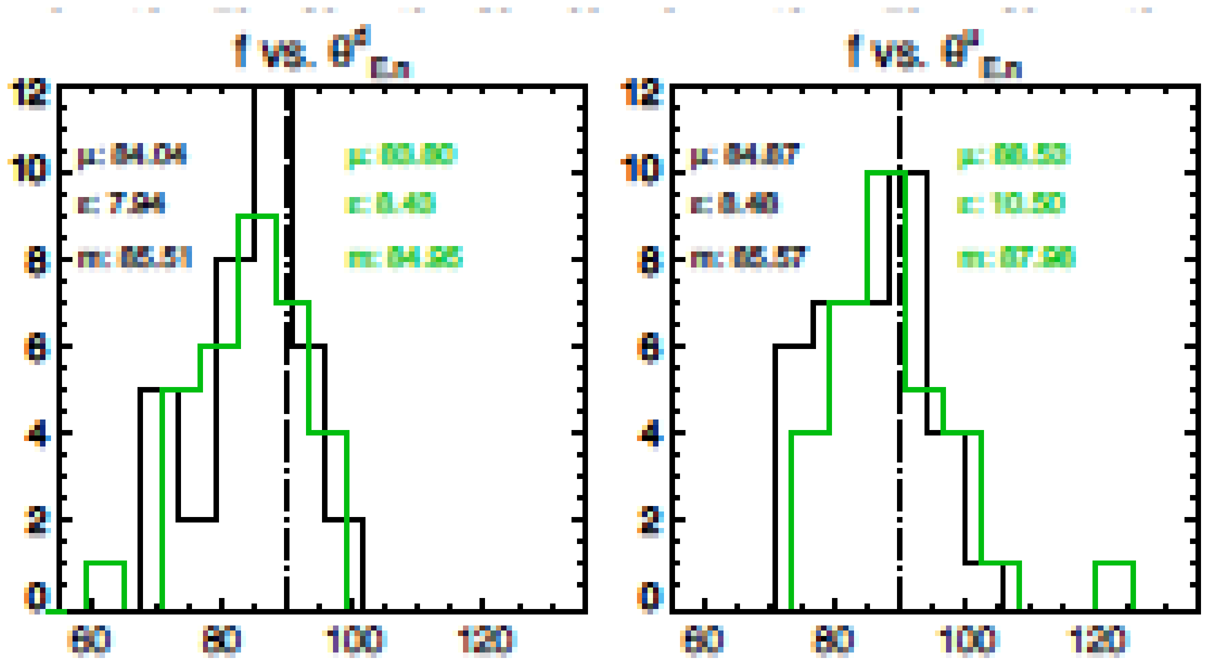
- Thomsen (1993) tested the *CS interaction model* using 9 ISEE HFA events found *E-field points inward* at least on one side of the discontinuity

- Schwartz (2000) extended the test to ~30 HFA events, found observations generally support the CS interaction model.

- 2D hybrid simulation model shows that CS interacts with the bow shock, reflected particles channeled into the CS, *temperature* increase which *expands* the CS and *excludes the SW*, reduces *density and magnetic field*. The expanding edges compress and form *shocks*. *No Instability* is involved (Thomas, 1991).

Statistical Analysis of Early phase DHs (35 events)

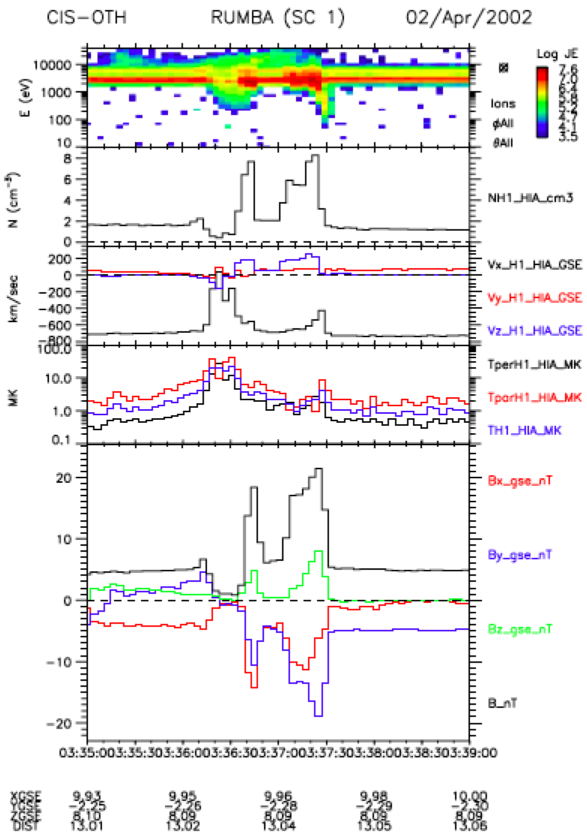




- Angle E-field to Current sheet normal.
- *Downstream* (C1=84.0±7.9°), (C3=83.8±8.4°);
- *Upstream* (C1=84.98.5°), (C3=88.5±10.5°)
- *Different from E-field in HFAs* which point inward (>90°)

C1 black; C3 green

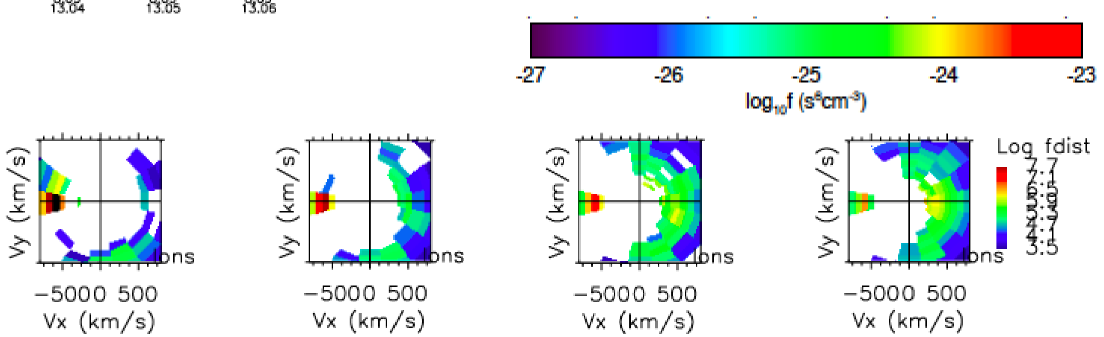
Wilber et al., 2008



HFA event (Lucek, 2004)

- *SW: Vx ~0* at 0336:22 UT
- However, SW ***beam*** is still present.
- SW beam ***velocity remains constant***, *~635 km/s.*

2D cuts of 3D *HFA* Distribution function (4s)



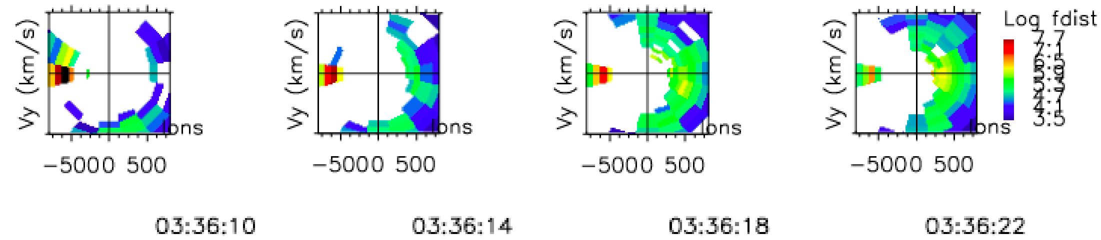
0336:12 0336:16 0336:20 0336:22

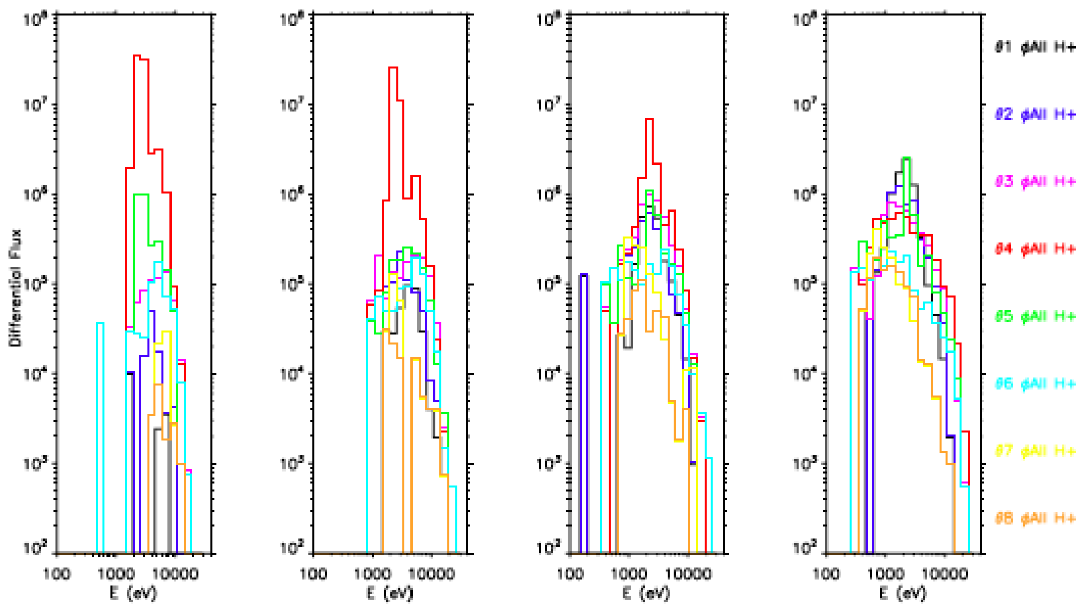
Intensity of the SW beam diminishes.

- 8 polar angles:

+90 to -90^o at 22.5^o.

- SW @ *θ4* and *θ5*.

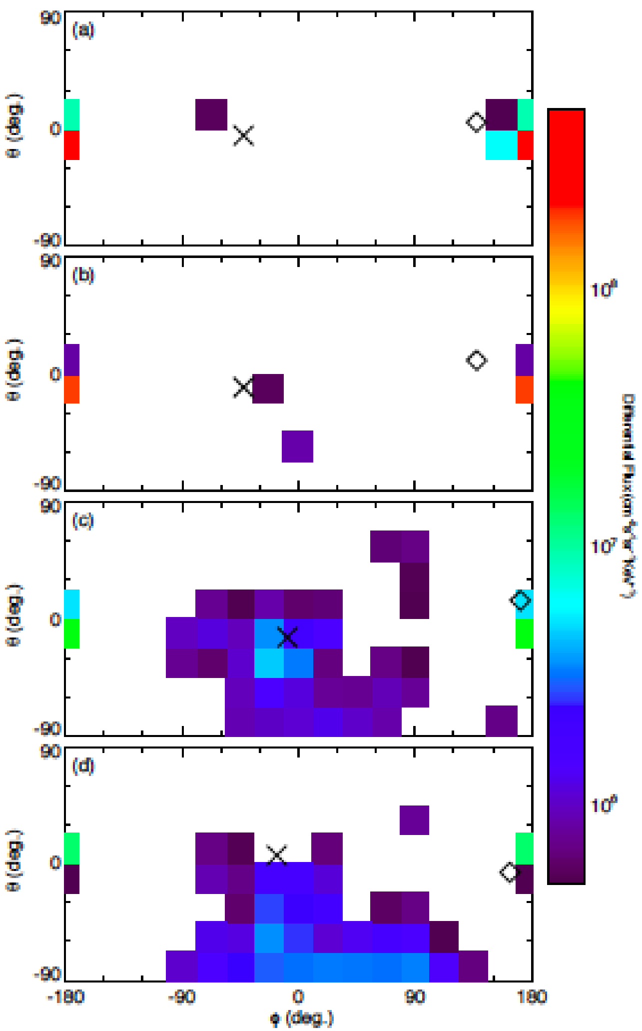




- SW ***intensity decreasing***.

- At the same time, ***fluxes from other directions are increasing***.

θ - ϕ Plot

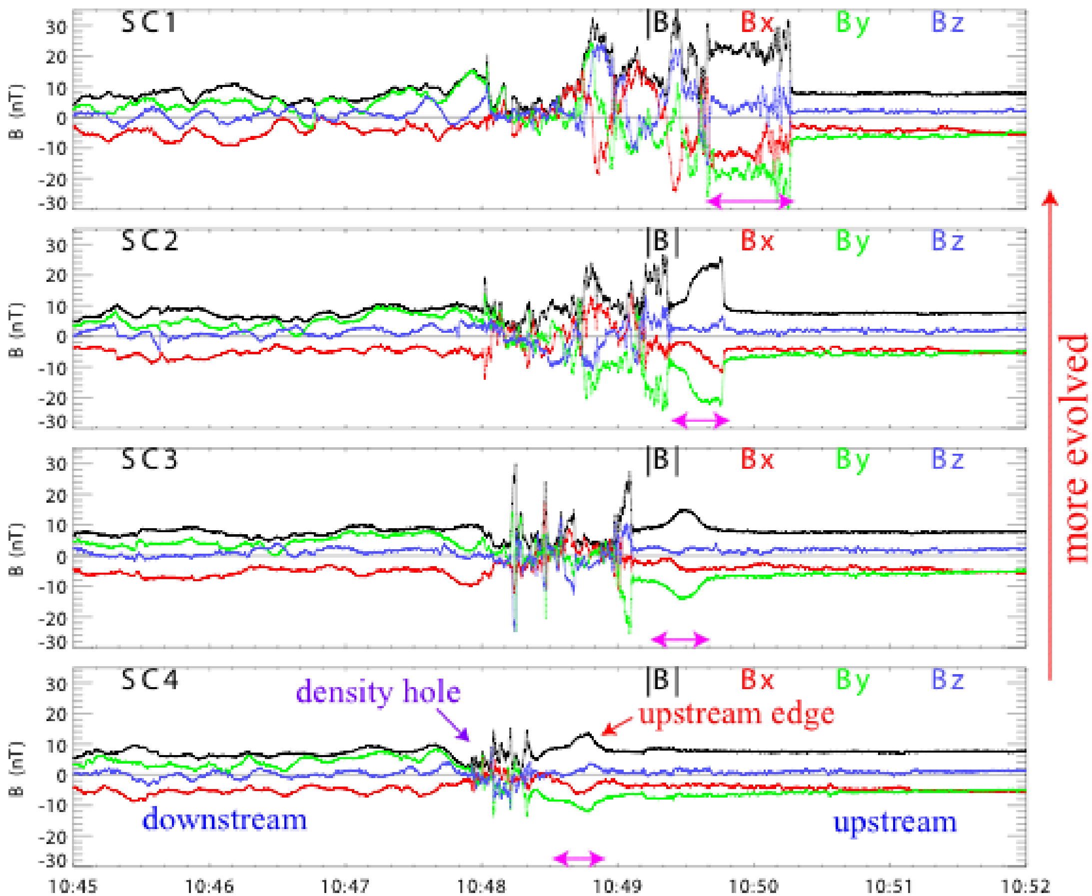


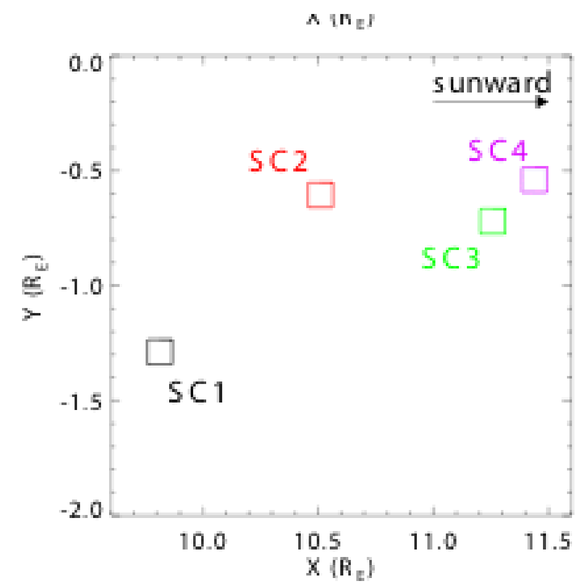
- As SC spins, distribution function obtained in 32 energy steps and 16 φ directions.
- *SW* at $\varphi = \pm 180^o$
- Fluxes at $\varphi = 0^o$, *opposite of SW*.
- *Flux buildup* $\varphi = 0^o$ as *SW intensity decreases*
- $V = \int v\, f\, d^3v \sim 0$ *back streaming contribution cancels* SW.

Parks et al., 2013

Magnetic field measurements (FGM) on Feb. 16, 2003

- 4 SC moving earthward
- Edge steepens into a shock
- CL1 hits bow shock 1210 UT





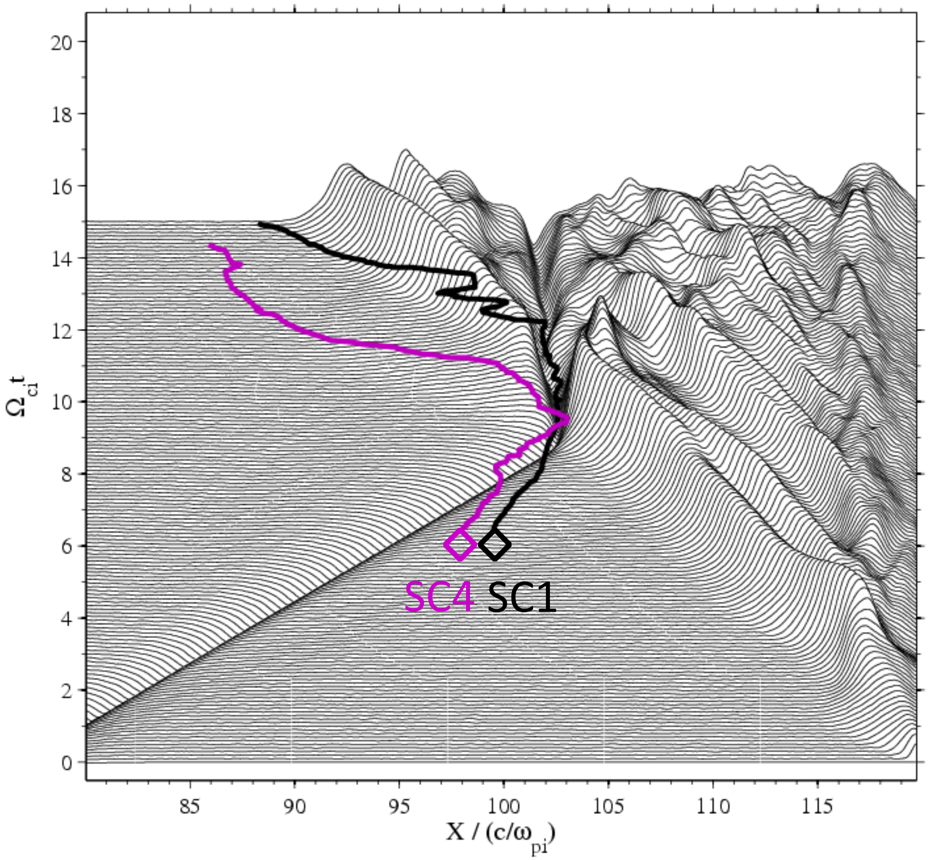
❑ Evolution sequence : SC4 → SC3 → SC2 → SC1

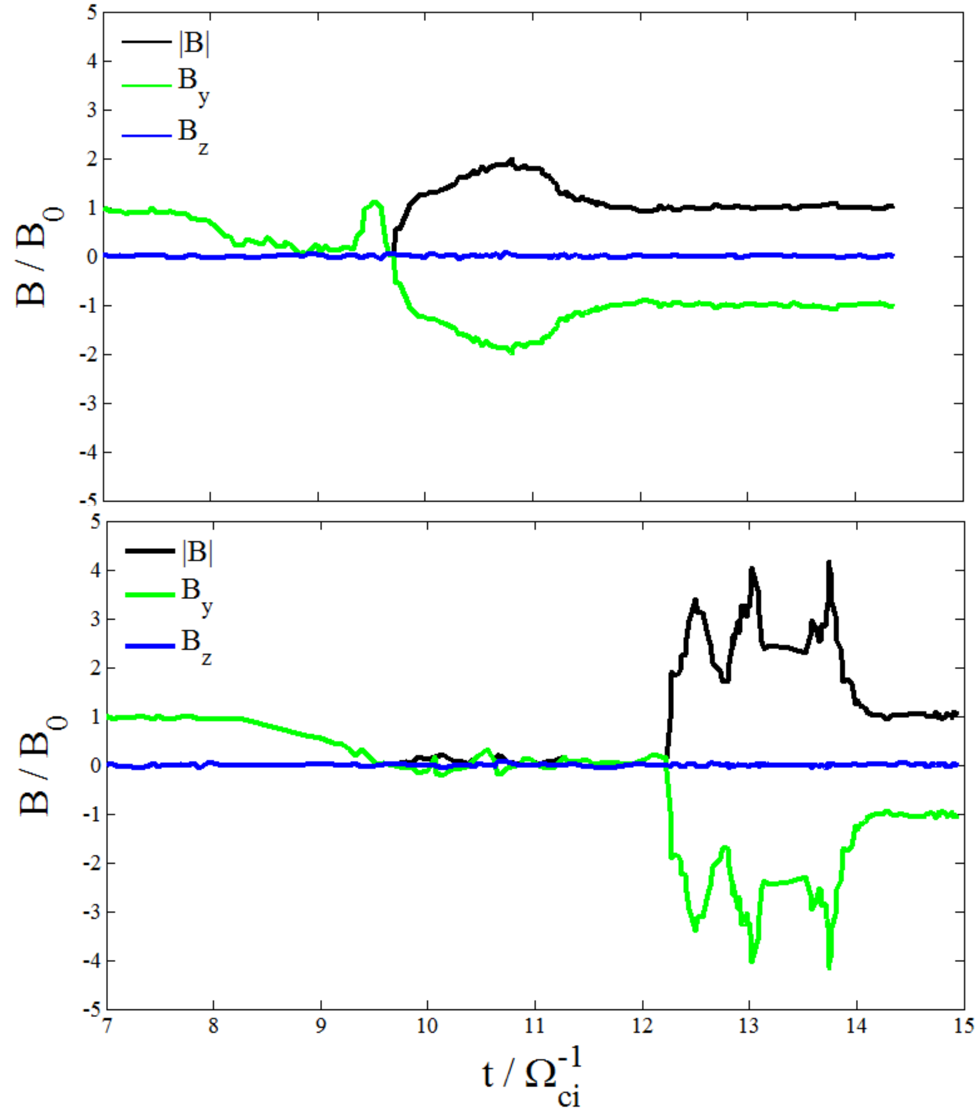
Lee et al., PRL, 2009

Nonlinear development of shock structure:

A perpendicular shock case ($\theta_{Bn}=90^o$, $M_A=4.5$, $\beta_i=1$, $\beta_e=0.5$)

[compare with Lee et al., PRL, 2009].

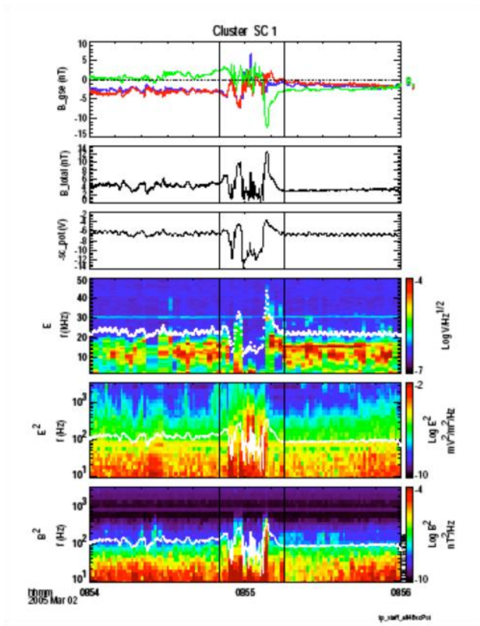


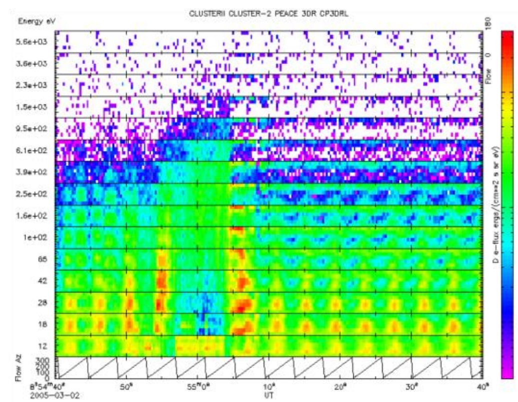


- IMF CS interaction with Bow Shock, originally suggested by Burgess and Schwartz (1988)

What have we learned?

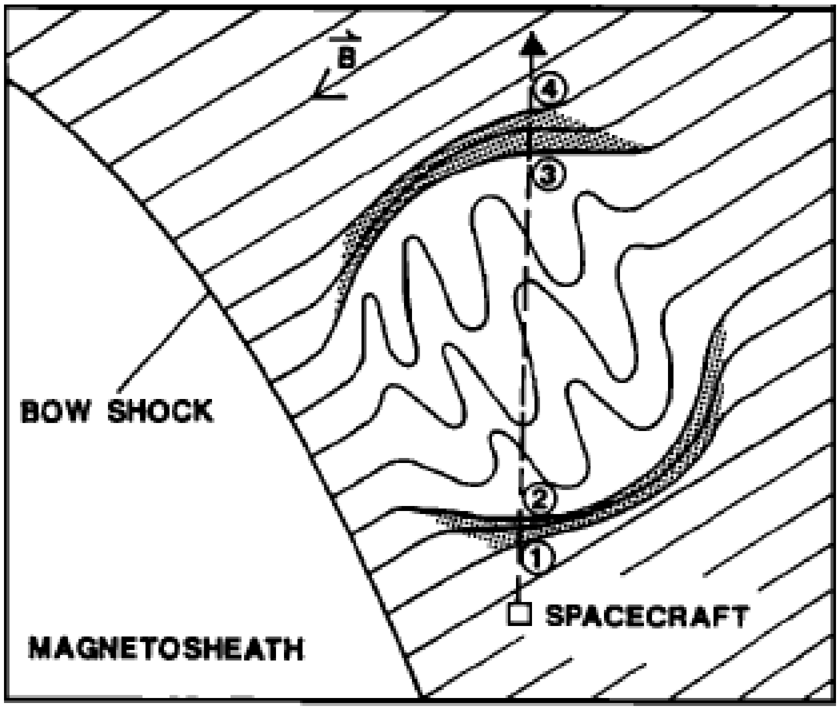
- ***Preliminary results of early phase DHs*** show different behavior than HFAs.
- Decrease of the SW $< V_x >$ in density depleted regions of *HFAs* is ***not*** due to ***blocking*** of the SW.
- SW beam is ***always present*** and the ***beam velocity*** remains fairly constant.
- ***Back Streaming particles*** + SW beam produces $<V> = 0$.
- Sunward streaming particles: SW ***reflected from bow shock*** + ***local source***
- Occupy large velocity space, ***T*** computed from ***second moment increases***.
- Multi-SC observations indicate nonlinear structures ***evolve in space and time*** and *duration* of events depends *how long the CS remains interacting* and on where measurement is made relative to the bow shock.


Cluster SC 1
B_gse (nT)
B_total (nT)
-sc_pot (V)
E
f (kHz)
Log V/Hz^1/2
E²
f (Hz)
Log E² mV²/m²/Hz
B²
f (Hz)
Log B² nT²/Hz
hhmm
2005 Mar 02
0854
0855
0856


CLUSTERII CLUSTER-2 PEACE 3DR CP3DRL
Energy eV
5.6e+03
3.6e+03
2.3e+03
1.5e+03
9.5e+02
6.1e+02
3.9e+02
2.5e+02
1.6e+02
1e+02
66
42
28
18
12
Flow Az
UT
2005-03-02
D e-flux ergs/(cm**2 s sr eV)

The End

Thomsen et al., (1988)



- Instability model:
- Reflected SW *couples* to incoming SW
- Excites Counter streaming *ion beam instability*
- *Heat particles*
- CS expands and *edges steepen*
- Produces HDCs.