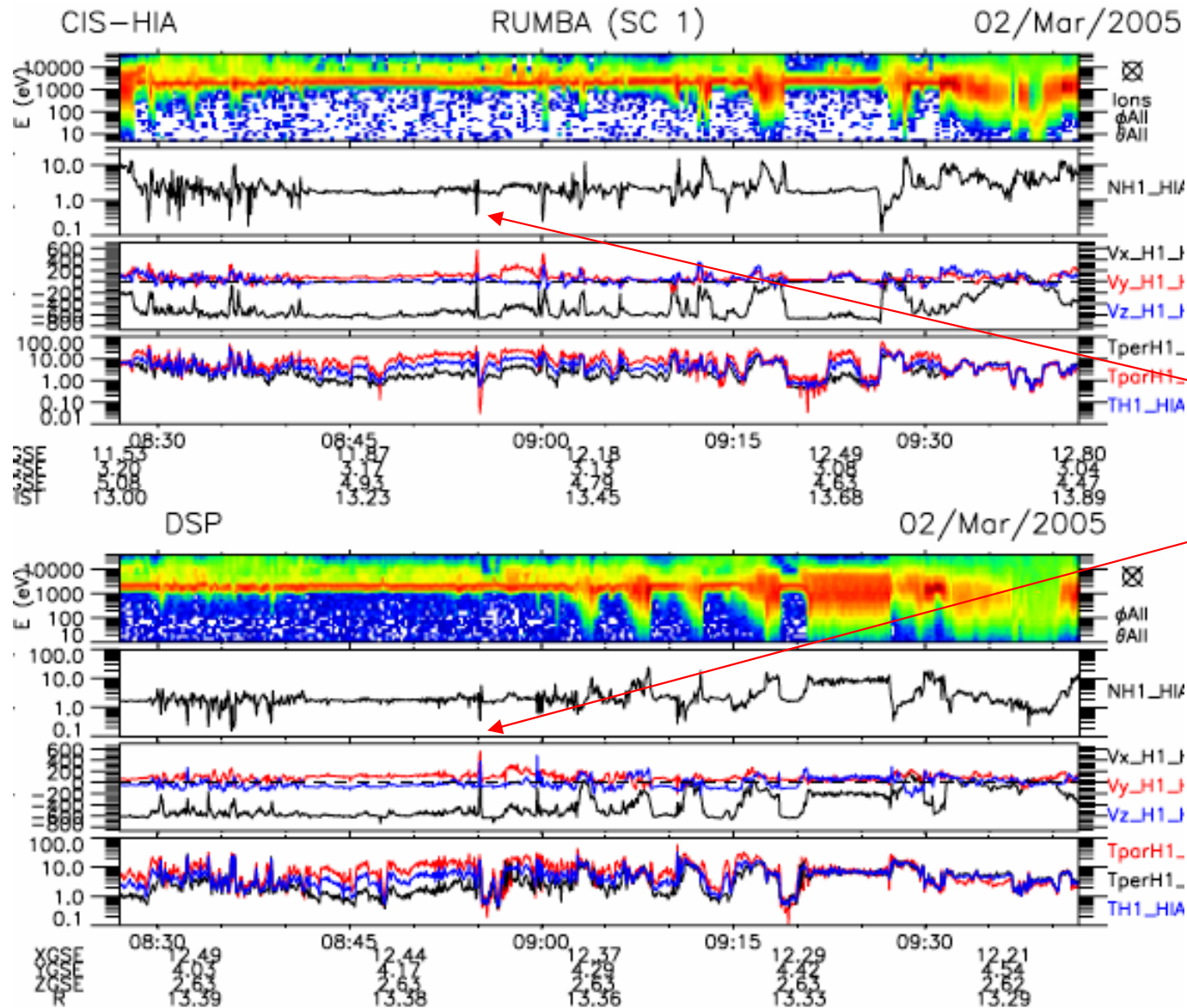


Larmor radius size density holes discovered in the solar wind upstream of Earth's bow shock

*G. K. Parks*¹, E. Lee¹, N. Lin¹, F. Mozer¹, M. Wilber¹, E. Lucek²,
I. Dandouras³, H. Rème³, J. Cao⁴, K. Meziane⁵, C. Mazelle³,
M. Goldstein⁶, P. Escoubet⁷, N. Cornilleau-Wehrin⁸,
P. Canu⁹ and P. Décréau⁹

1. Space Sciences Laboratory, UC Berkeley
2. Imperial College, London
3. CESR, Toulouse
4. Key Laboratory for Space Weather, Beijing
5. University of New Brunswick, New Brunswick
6. NASA - GSFC
7. ESA, Noordwijk
8. CETP/UVSQ, Velizy, France
9. LPCE and University of Orleans, Orleans, France

Observations of the upstream solar wind by Cluster and Double Star



What are the “spikes” that go above and below the ambient SW density levels?

Introduction

Known disturbances upstream of the bow shock

*Hot flow anomaly (**HFA**)/Hot diamagnetic cavity (**HDC**):*

Depressed B field filled with hot plasma flowing deflected from the solar wind direction (Schwartz, 1985; Thomsen, 1986)

*Short, Large Amplitude Magnetic Structures (**SLAMS**):*

Enhancement of B at least 2-4 times the solar wind field (Schwartz, 1991; Giacalone, 1993)

*Foreshock cavity (**FC**):* Diamagnetic cavity filled with slightly hotter plasma than SW and flowing in nearly the same direction as the solar wind (Sibeck, 2002)

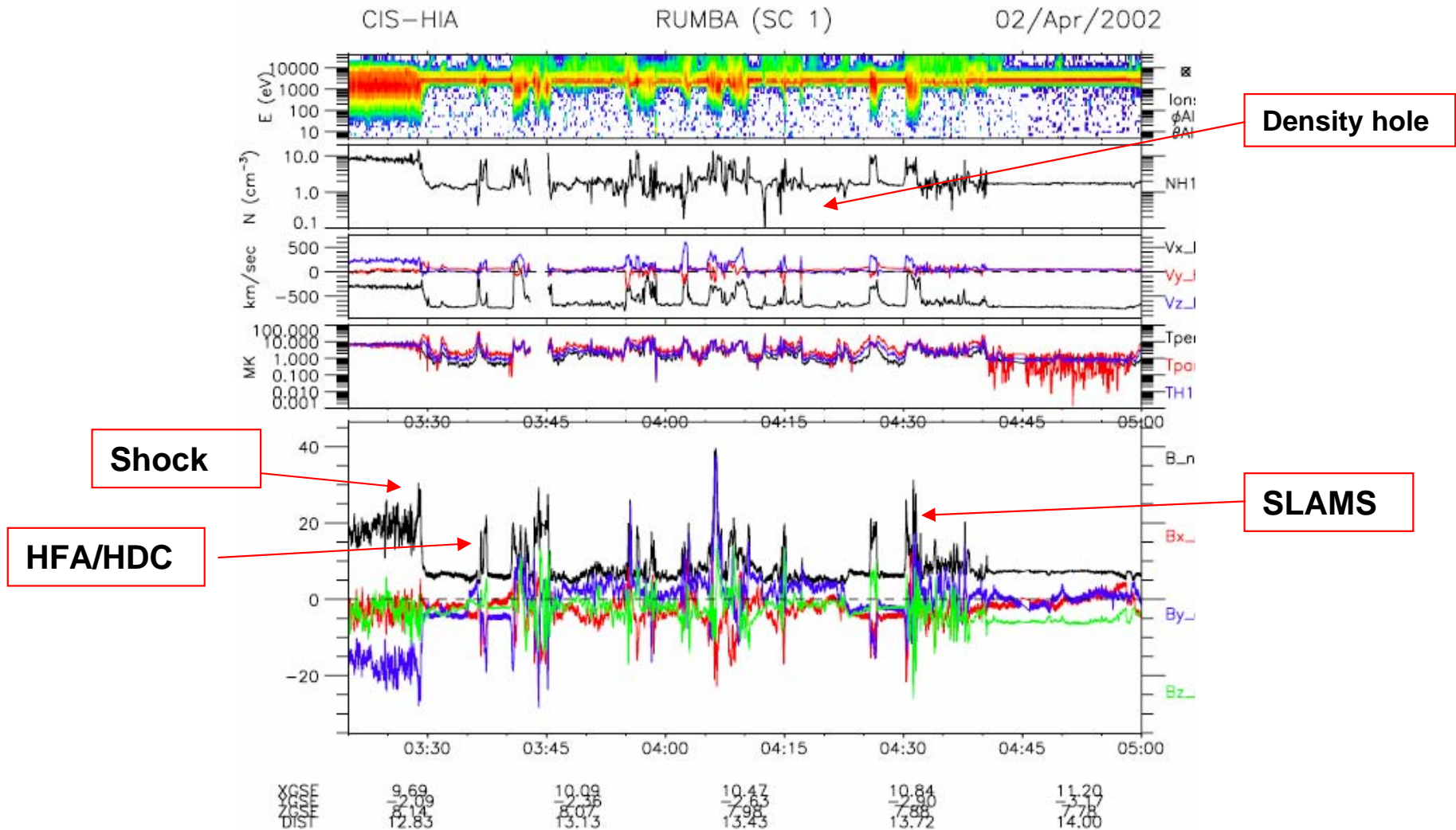
Density hole: *Ion Larmor size structure with density depleted at the center and enhanced at the edges*

Similarities and differences

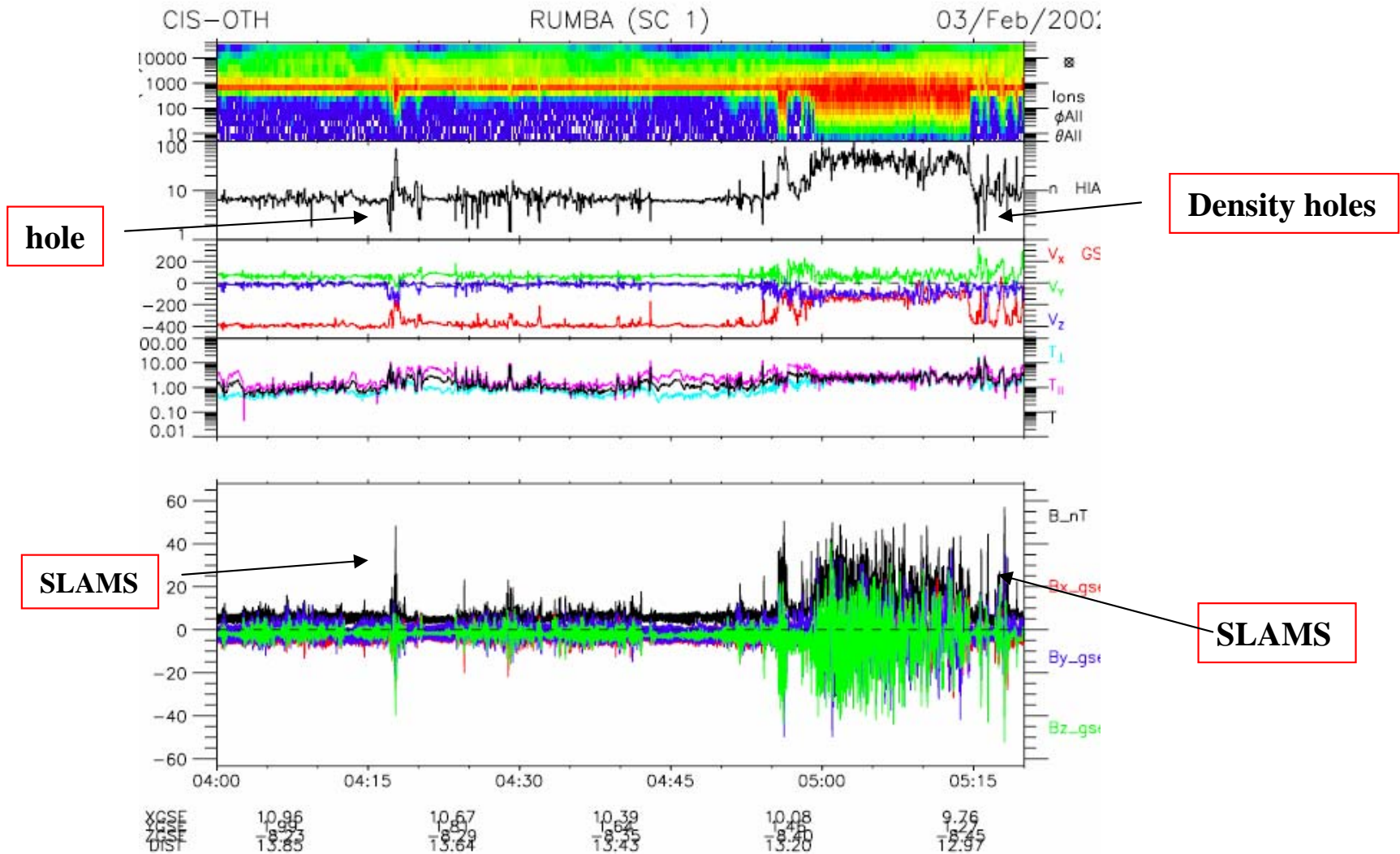
Density holes, HFA/HDC, FC and SLAMS

	DH	HFA/HDC	FC	SLAMS
Duration	~18 s	~few minutes	>few minutes	~10-20 s
Scale length	$\sim R_{\perp}$	$\sim R_E$	>few R_E	$\sim R_E$
$\delta n/n$	0.7	< 0.2	< 0.2	No report
Bulk V	$V_x \rightarrow \sim 0$	$V_x \rightarrow -100$	$\sim V_{sw}$	No report
T (hole)	$\sim 10^{6-7}$	$\sim 10^6$	$> 10^5$	No report
Overshoot	yes	yes	yes	yes
Shock-like?	yes	yes	no	yes
Occurrence	Frequent	Rare	Rare	Frequent
E-field	yes	No report	No report	yes
Waves	yes	No report	No report	No report
Backstream ions	yes	yes	No report	No report
Electron hole	yes	No report	No report	No report
Currents J	yes	No report	No report	Inferred

HFA/HDC and SLAMS on April 2, 2002 by Cluster included density holes



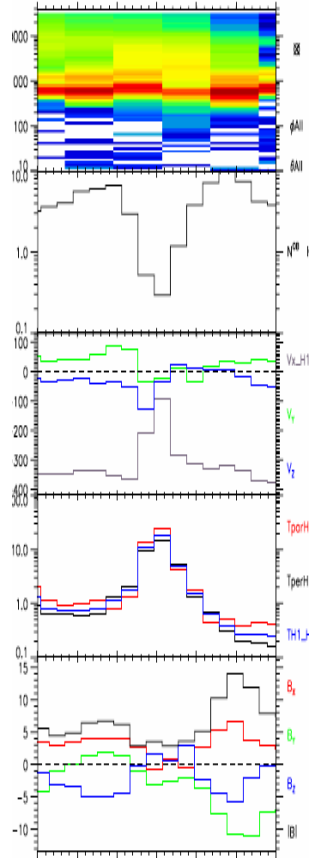
SLAMS observed on 3 February 2002 by Cluster included density holes



Examples of Density Holes, SLAMS and HFA/HDC

Double Star

24-Feb-04

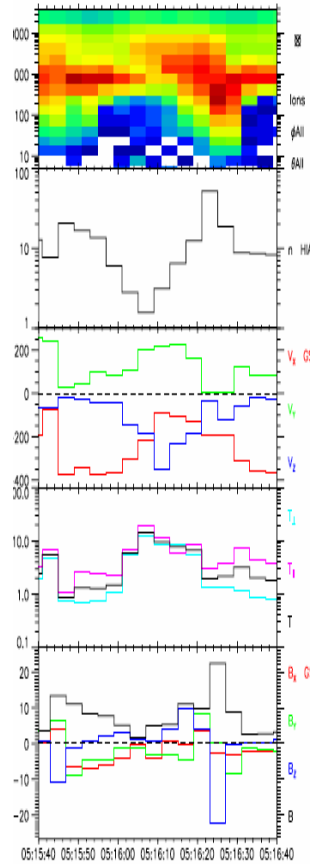


0649:30

0650:30

SLAMS

C1 3 Feb 02

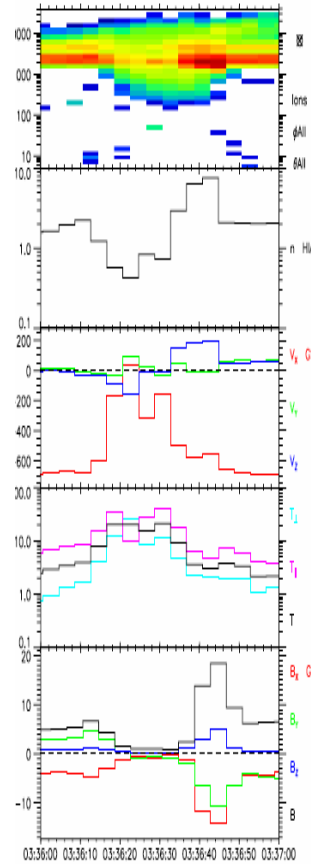


0515:40

0516:40

HFA/HDC

C1 2 Apr 02



0336

0337

← E-flux

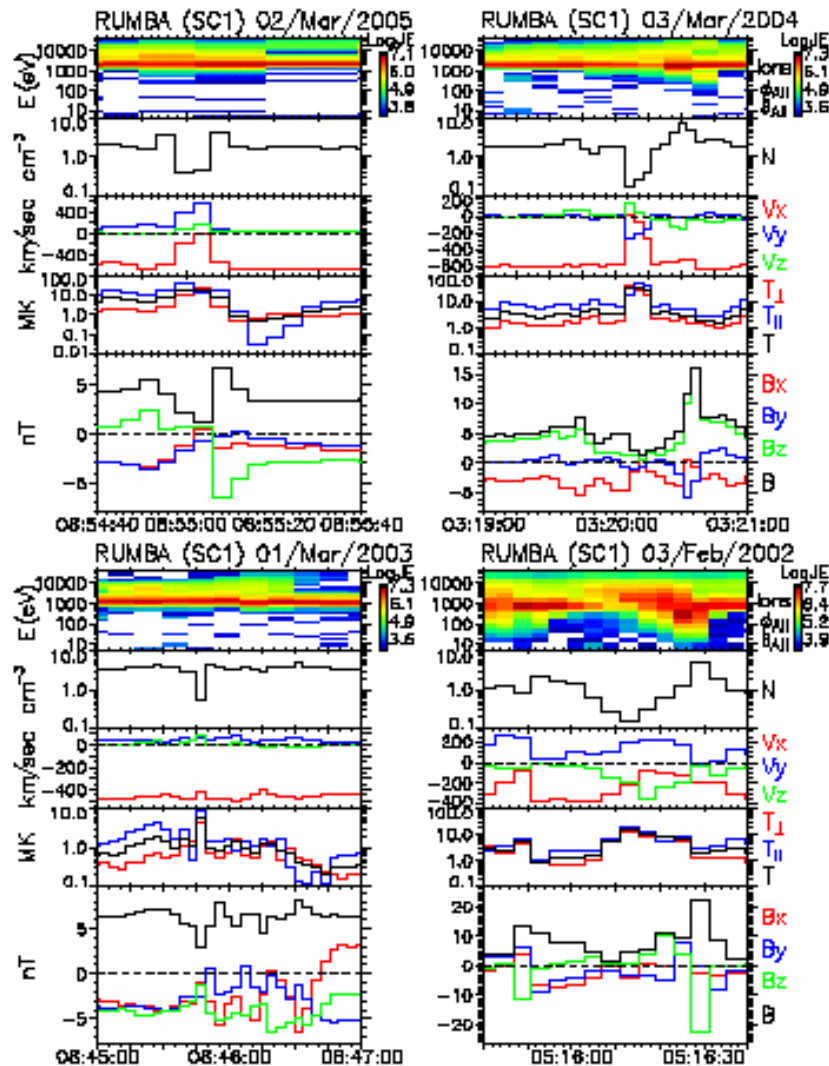
← n

← V

← T

← B

More Examples of Density Holes



Properties of Density holes

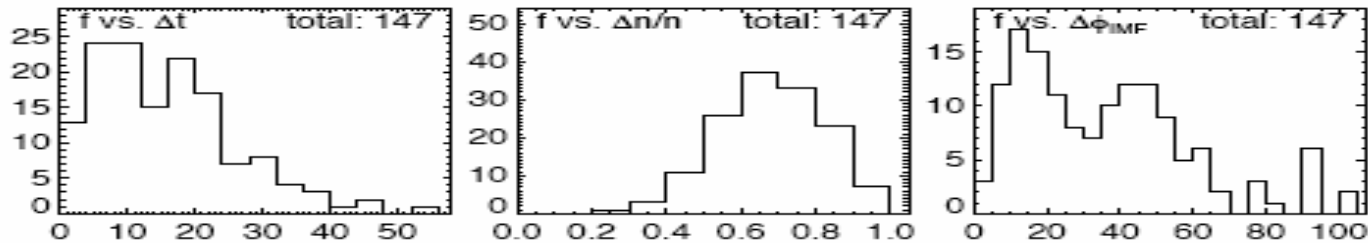
- typical duration ~18s but some as short as 4s
- symmetric + asymmetric
- depletions $\delta n/n \sim 0.6-0.98$
- usually accompanied by similarly shaped B-holes
- Large variation of B and one/two components change sign. Bx is small.
- Holes tend to become smaller with distance away from the bow shock and the bulk parameters do not deviate much

Statistical studies of ~150 events

$$\Delta t \sim 18 \pm 10 \text{ s}$$

$$\delta n/n \sim 0.7 \pm 0.14$$

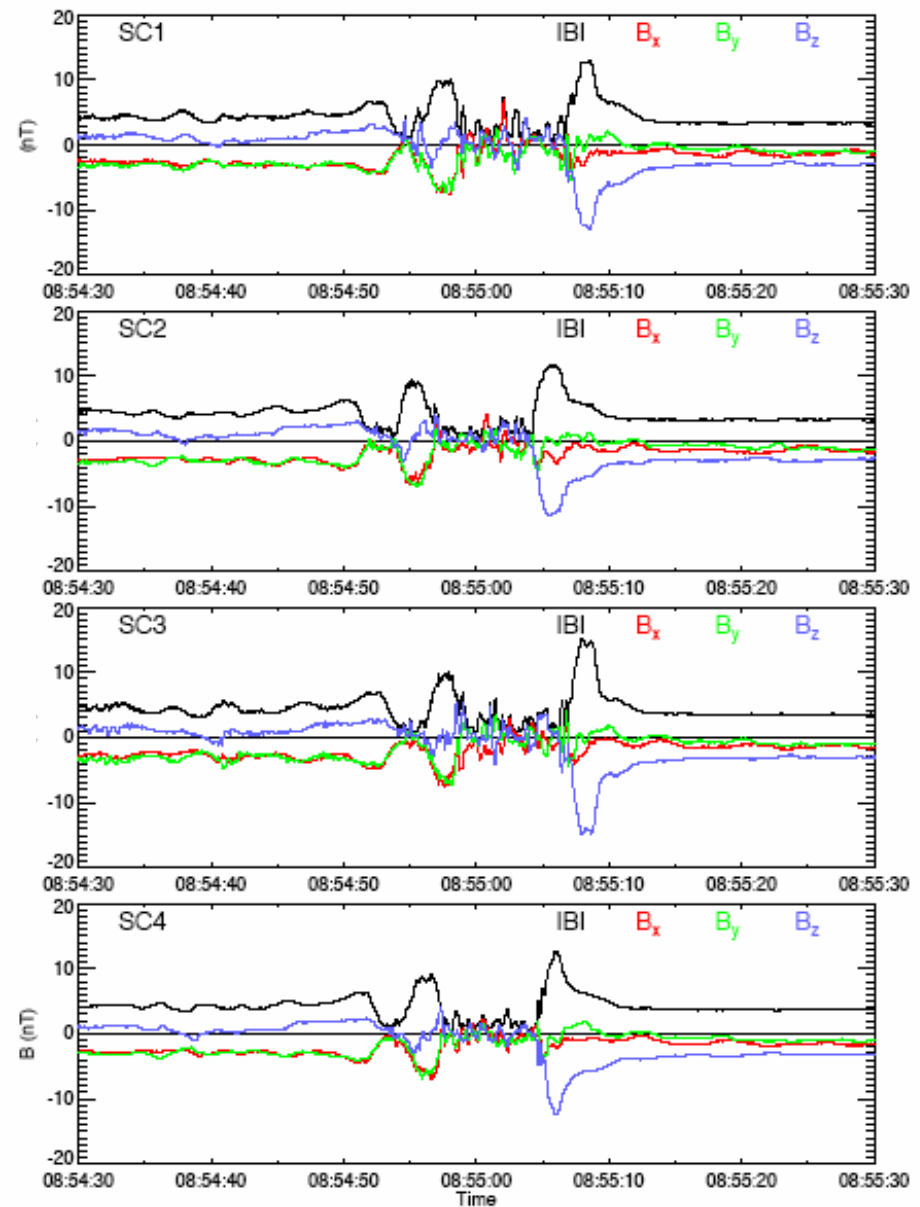
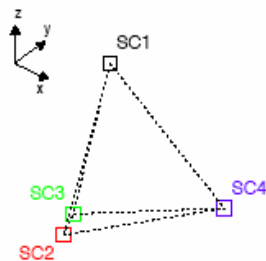
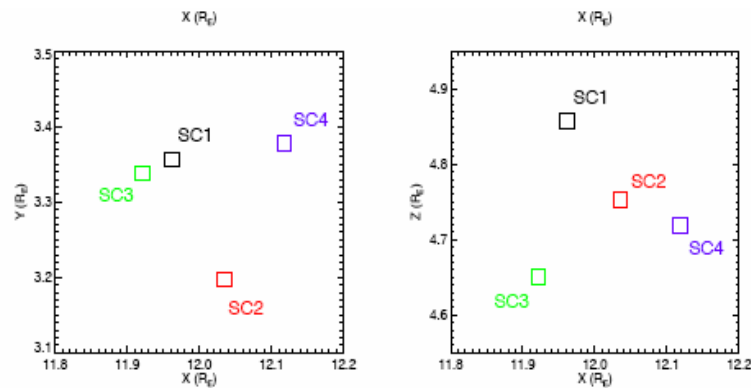
$$36^\circ \pm 24^\circ$$



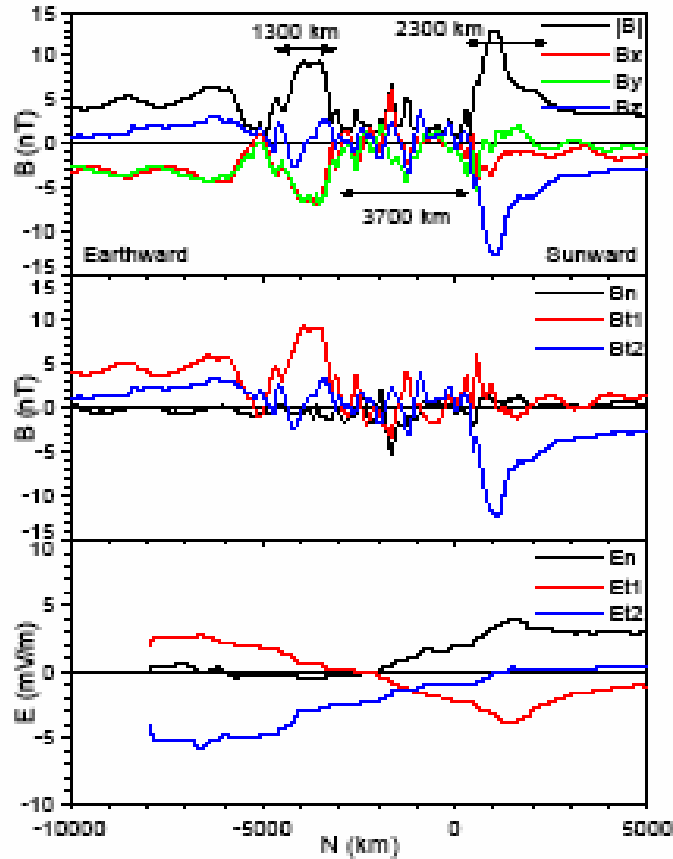
Properties of Density holes

- typical duration ~ 18 s but some as short as 4s
- depletions $\delta n/n \sim 0.6-0.98$
-

4SC Hi-Res_B (2 March 2005)



Lagrangian view of a density hole



Downstream edge

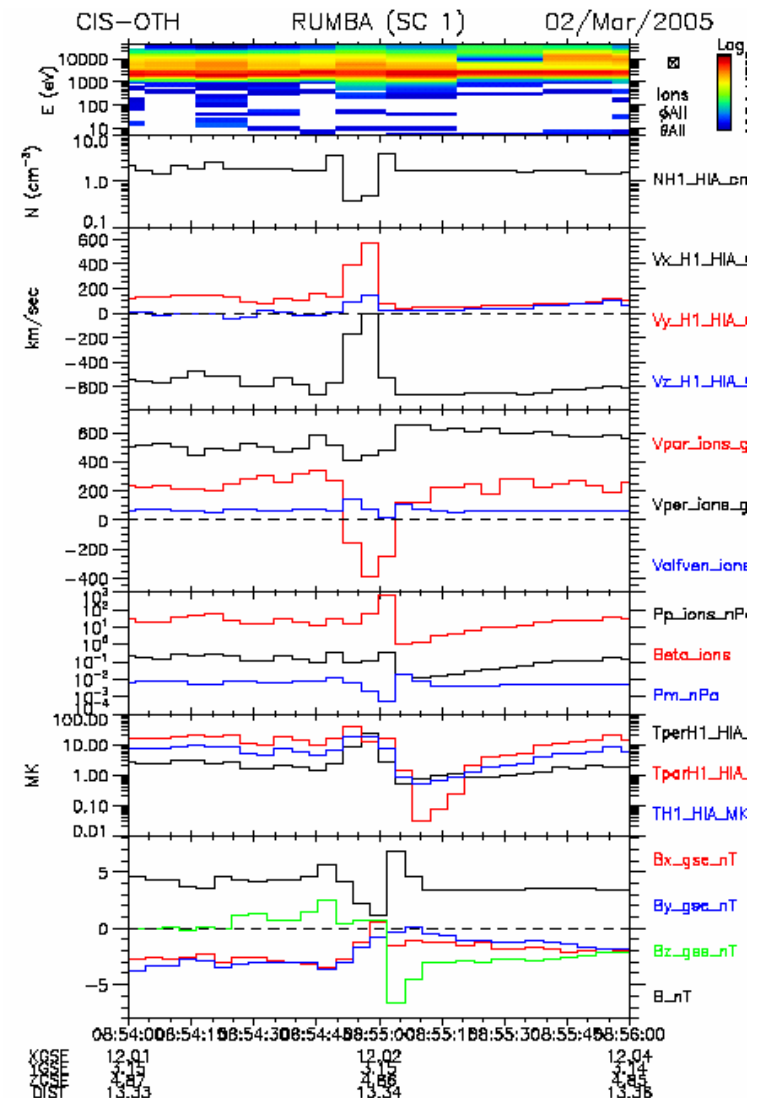
$$V \sim 530 \text{ km/s}$$

$$a \sim 56 \text{ km/s}^2$$

Upstream edge

$$V \sim 320 \text{ km/s}$$

$$a \sim -23 \text{ km/s}^2$$

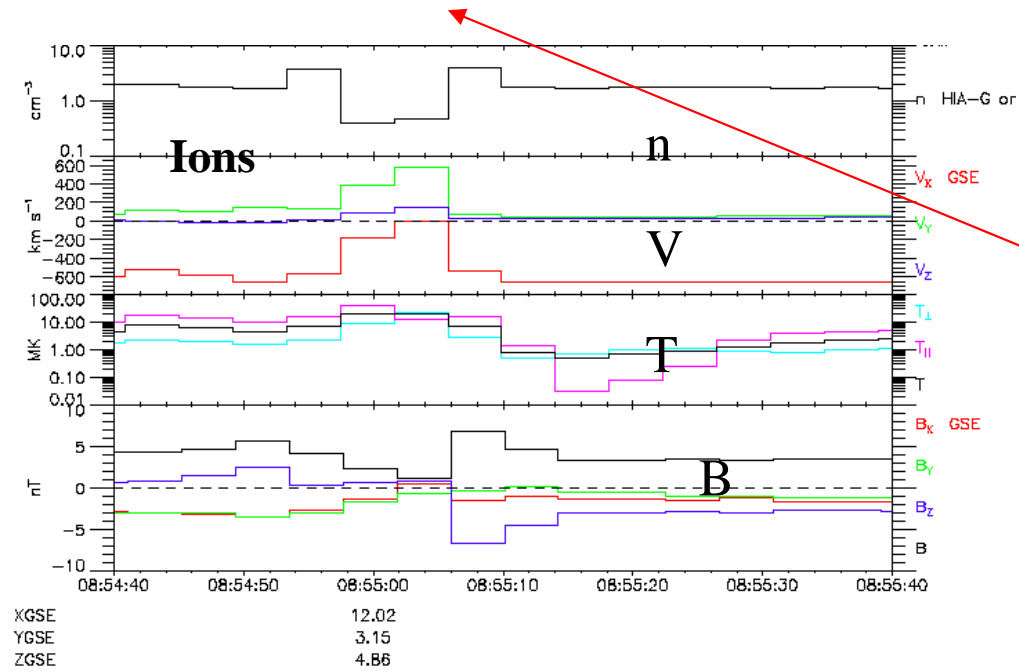


Electron Pitch-angle Spectrogram

Electrons

QuickTime™ and a TIFF (LZW) decompressor are needed to see this picture.

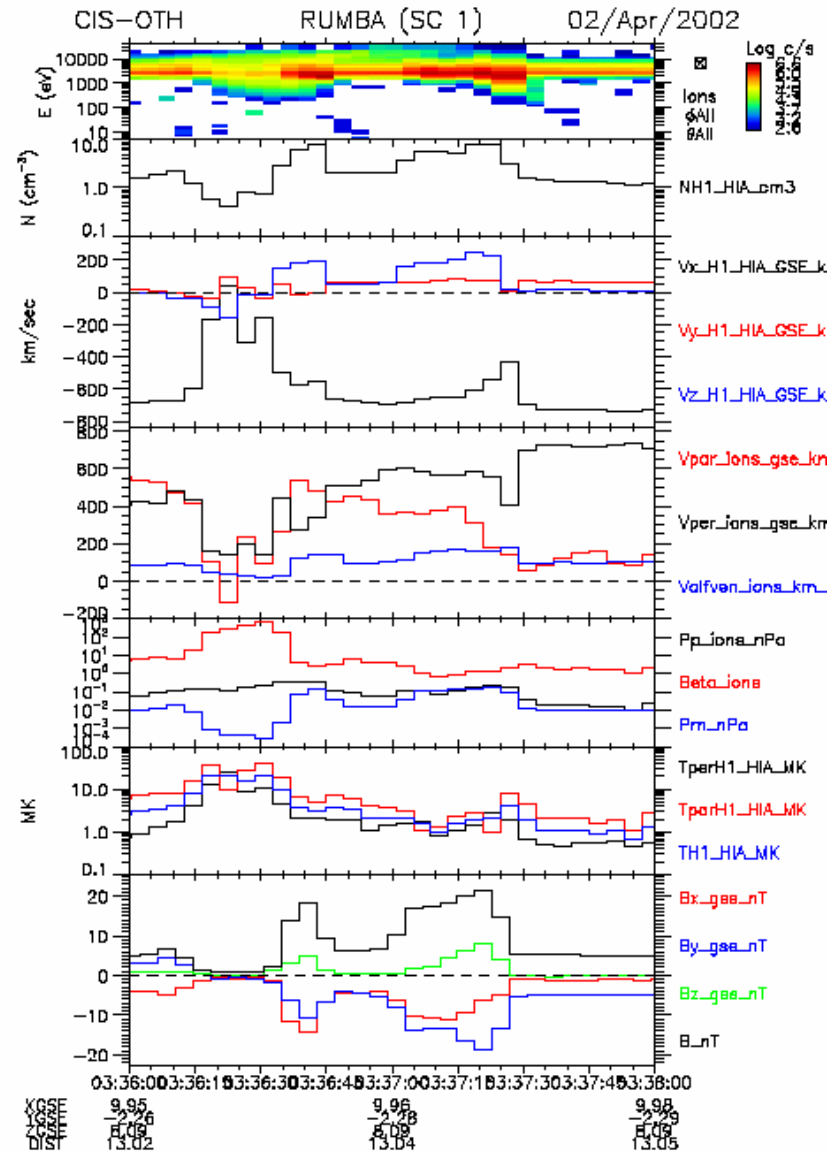
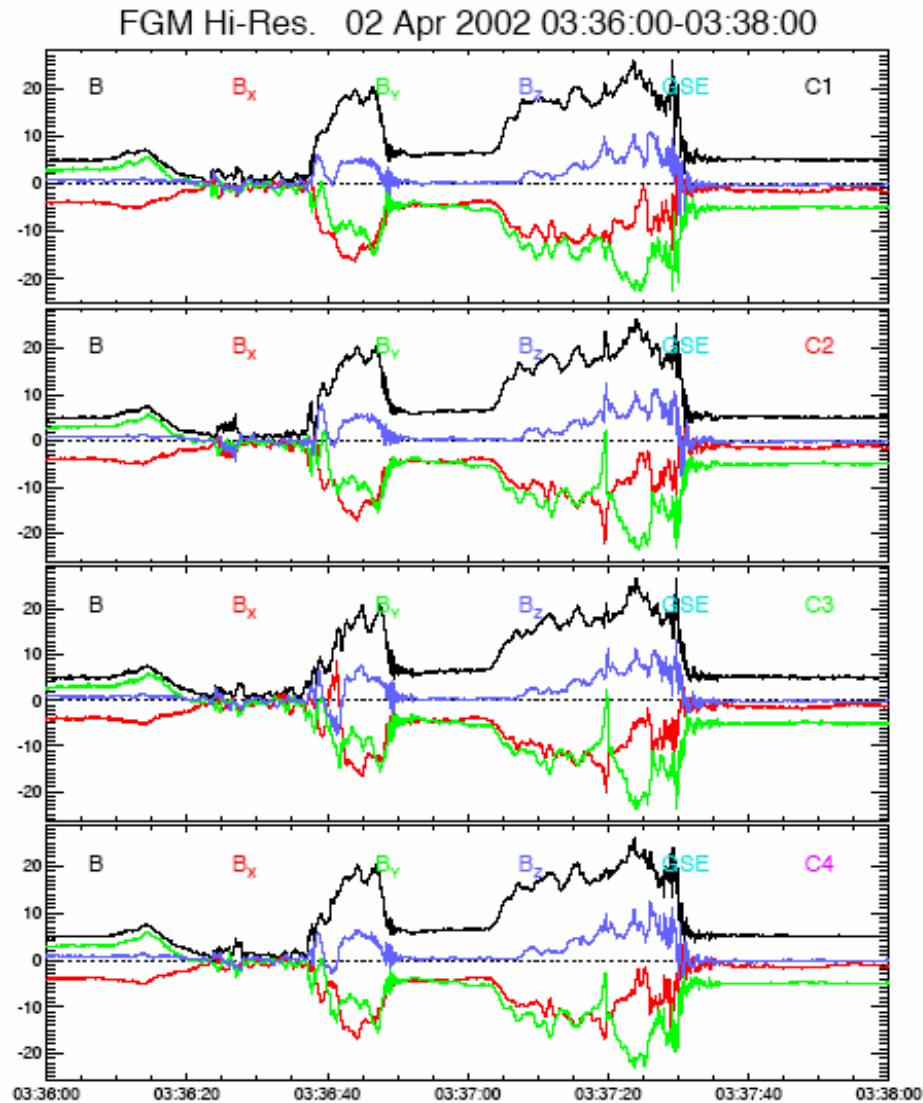
Field-aligned, 0°



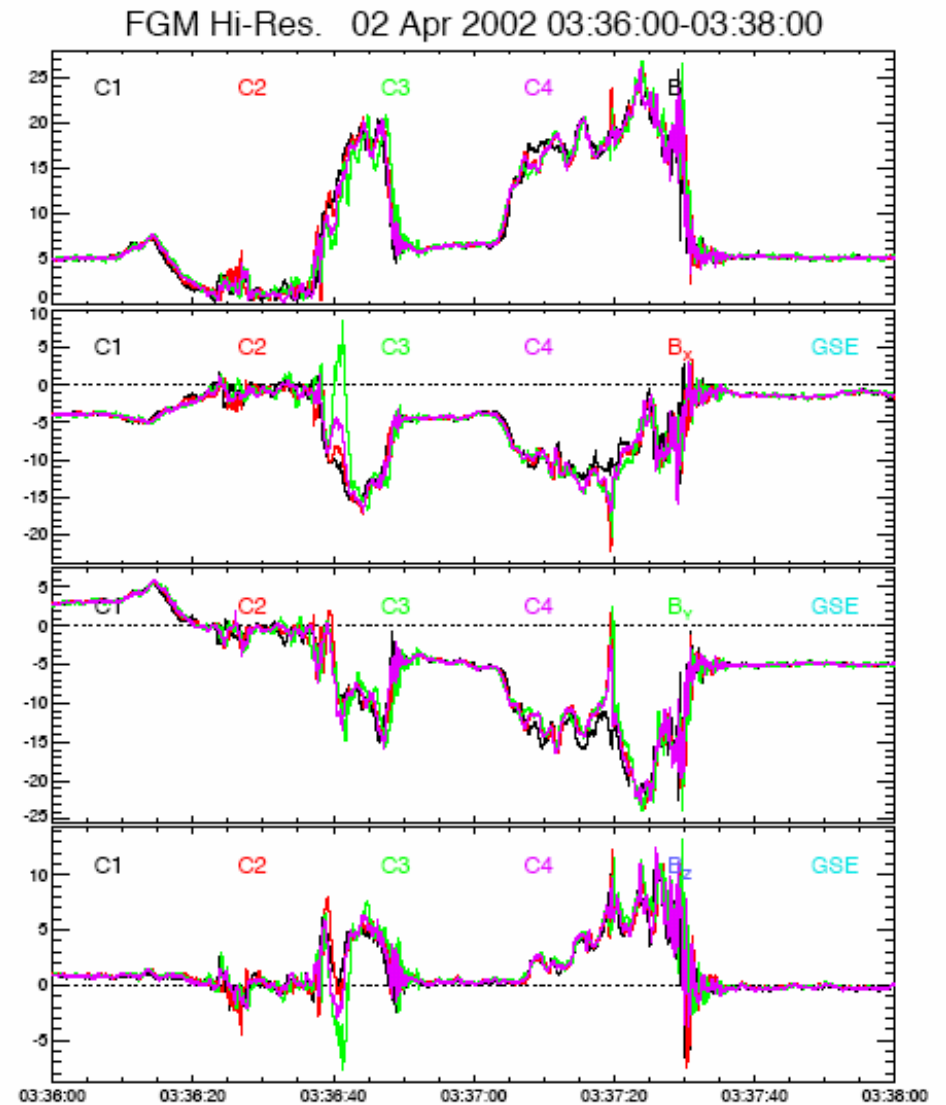
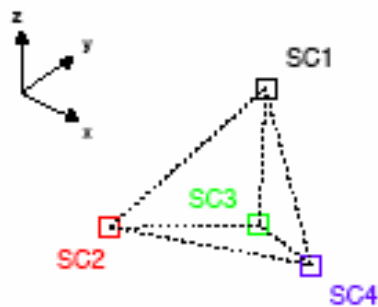
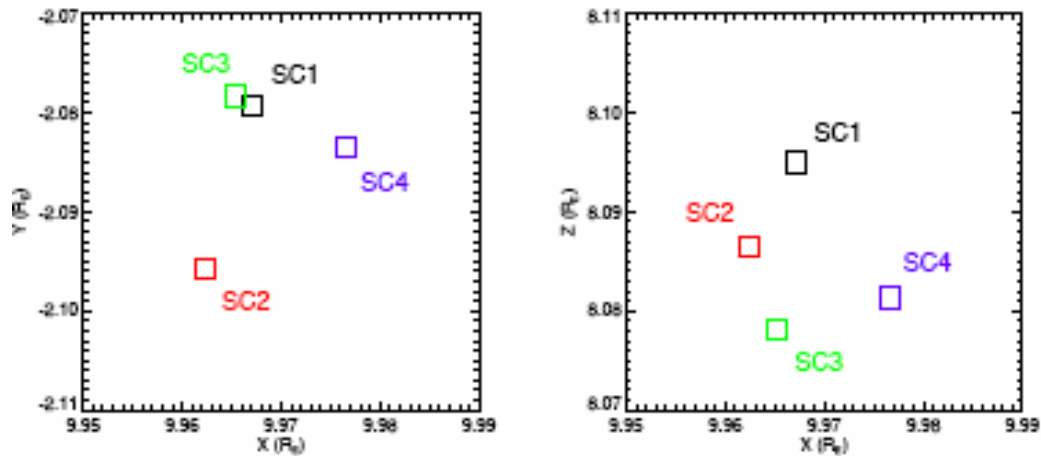
Field-aligned, 180°

High Resolution B₄ SC -HFA/HDC

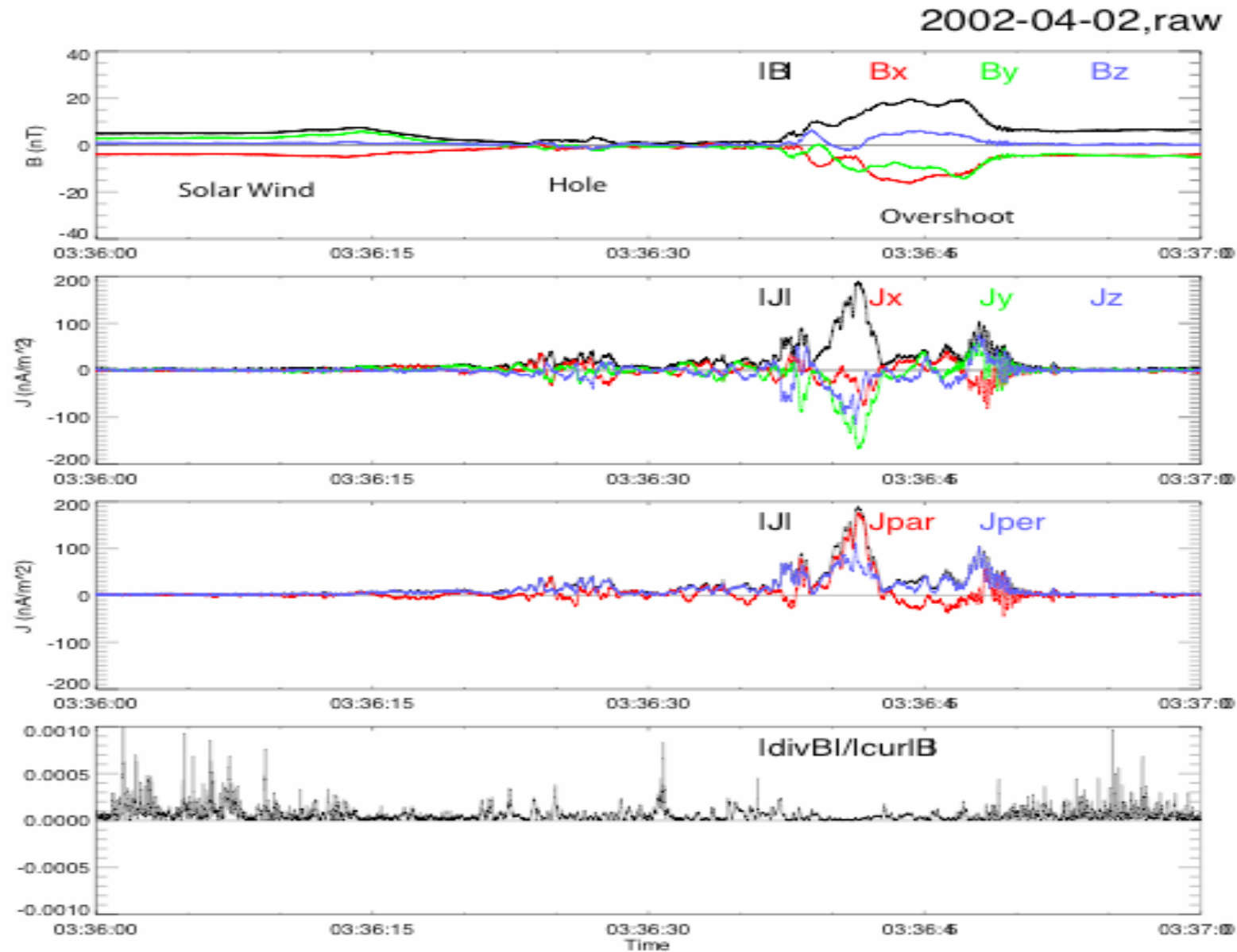
(02 April 2002)



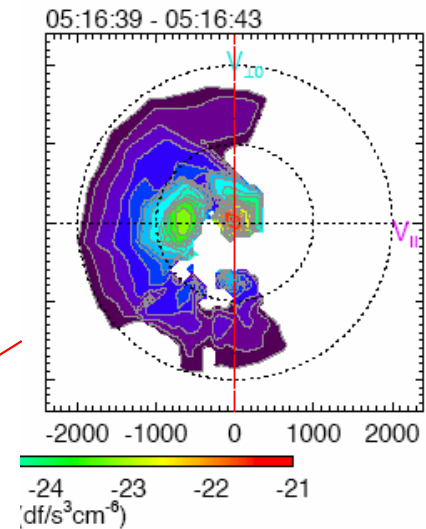
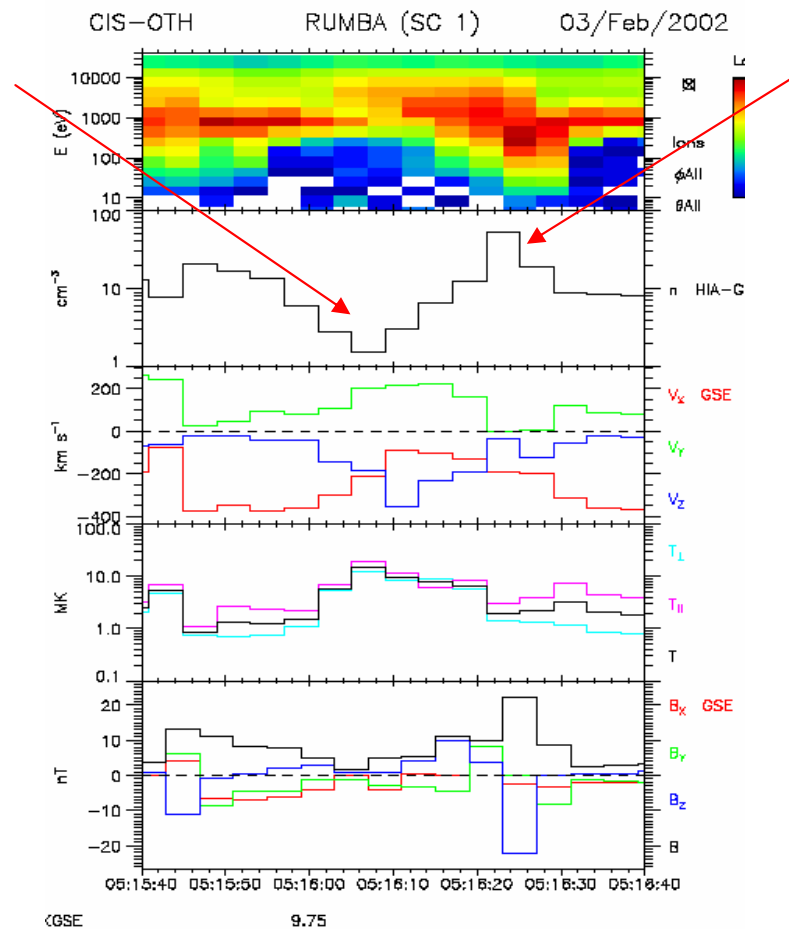
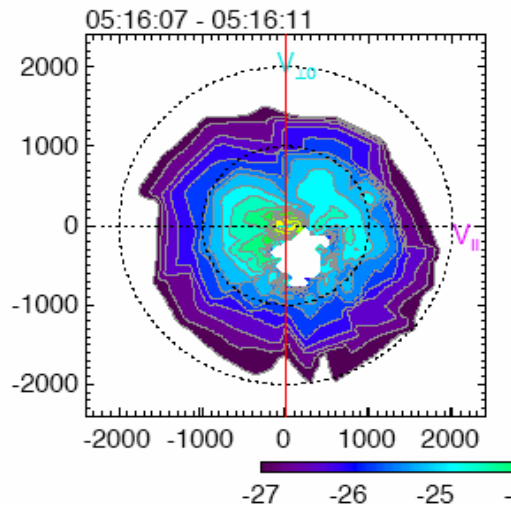
4SC Magnetic Field Observations (2 April, 2002)



Currents in Density holes

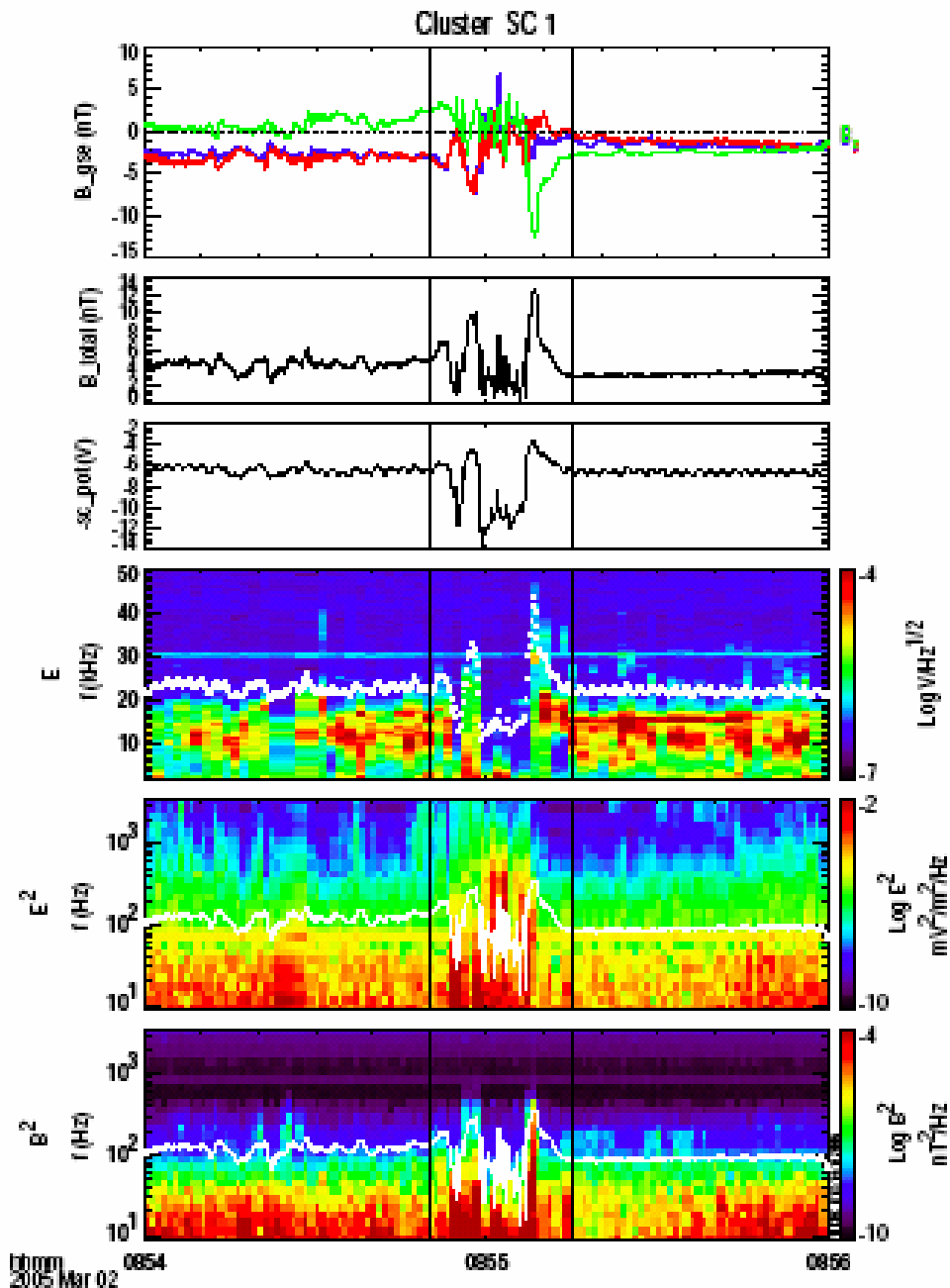


Ion distribution function inside the hole and edge (SLAMS)



Similar to ion distributions seen upstream of the bow shock

Waves and density holes



- EM Waves up to electron cyclotron frequency at the edges (Whistlers)
- Electrostatic waves inside the hole

Naiguo Lin

Poster

Summary (Parks et al., PoP 13, 050701, 2006)

- Density holes observed for $400 < V_{sw} < 800$ km/s, $n \sim 1-10$ /cc, $T \sim 10^5-10^6$ °K, in both quasi-parallel and quasi-perpendicular regions. Seen out to $19 R_E$.
- Density holes observed in ions, electrons and EM fields. Duration as short as 4s, dimension as small as gyroradius, SW diverted and T increases inside holes. Holes are dynamic. Holes evolve in space and time. Density holes are associated with HFA/HDC and SLAMS.
- Deep holes and large overshoots can have shallow and weak **B** overshoots and vice versa. Energetic electrons ~ 10 's of keV seen at the edges.
- Ion distributions near the edges behave like they do in front of the bow shock. Low frequency ES waves inside density holes could heat electrons. Strong electron currents at the steepened edge.
- Energetic backstreaming particles *always* present. But *not* all upstream particles accompanied by density holes.

What creates the density depletion and nonlinear steepening of the edges?

What is the relationship between density holes and the bow shock?

The End