Statistics and accuracy of magnetic null identification

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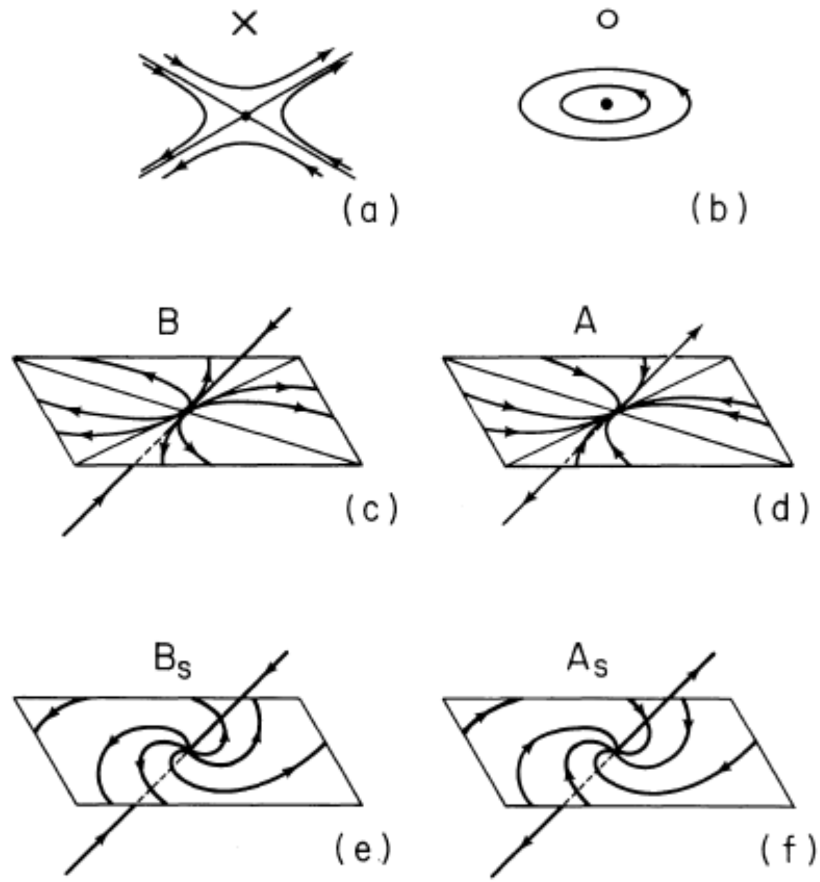
Introduction - Magnetic Nulls

Regions with vanishing magnetic field values are referred to as **magnetic nulls**.



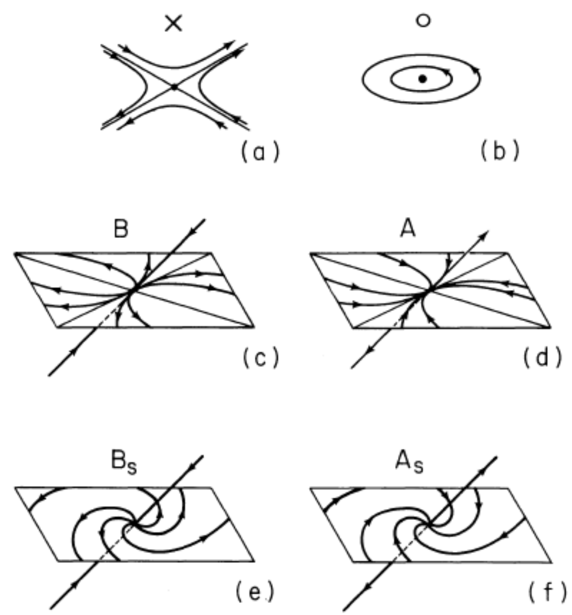
(Lau and Finn, ApJ, 1990)

Introduction - Type

The type of the magnetic nulls are identified using Lau and Finn's, ApJ, 1990, classification by calculating the eigenvalues of $\nabla\mathbf{B}$.

$$\nabla\mathbf{B} = \begin{bmatrix} \frac{\partial B_x}{\partial x} & \frac{\partial B_x}{\partial y} & \frac{\partial B_x}{\partial z} \\ \frac{\partial B_y}{\partial x} & \frac{\partial B_y}{\partial y} & \frac{\partial B_y}{\partial z} \\ \frac{\partial B_z}{\partial x} & \frac{\partial B_z}{\partial y} & \frac{\partial B_z}{\partial z} \end{bmatrix}$$

λ_1	λ_2	λ_3	Type
0	$+\lambda$	$-\lambda$	X-point
0	$+i\lambda$	$-i\lambda$	O-point
$-\lambda_1$	$-\lambda_2$	$(\lambda_1+\lambda_2)$	A
$+\lambda_1$	$+\lambda_2$	$-(\lambda_1+\lambda_2)$	B
$+\lambda_1$	$-\lambda_1/2+i\lambda_2$	$-\lambda_1/2-i\lambda_2$	A_s
$-\lambda_1$	$+\lambda_1/2+i\lambda_2$	$+\lambda_1/2-i\lambda_2$	B_s



(Lau and Finn, ApJ, 1990)

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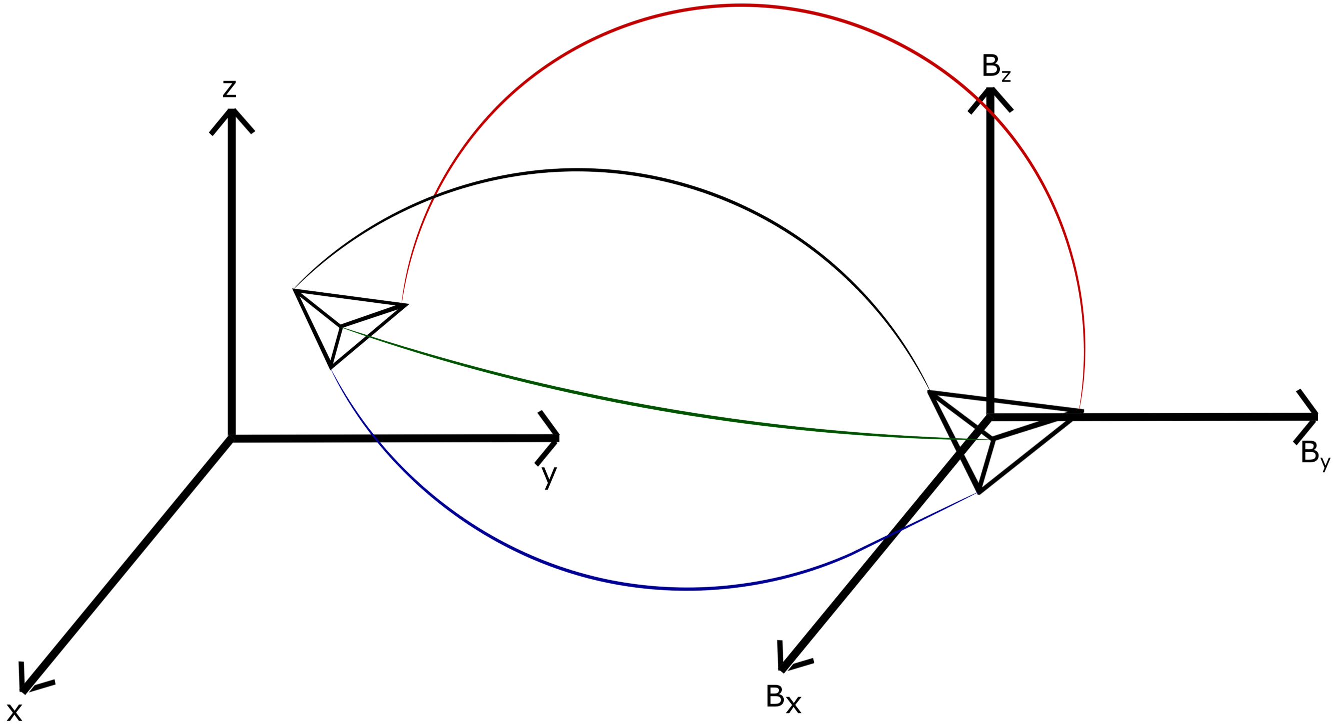
Introduction - Why

- Useful tool to characterize complex 3D magnetic topologies
- Important in 3D reconnection

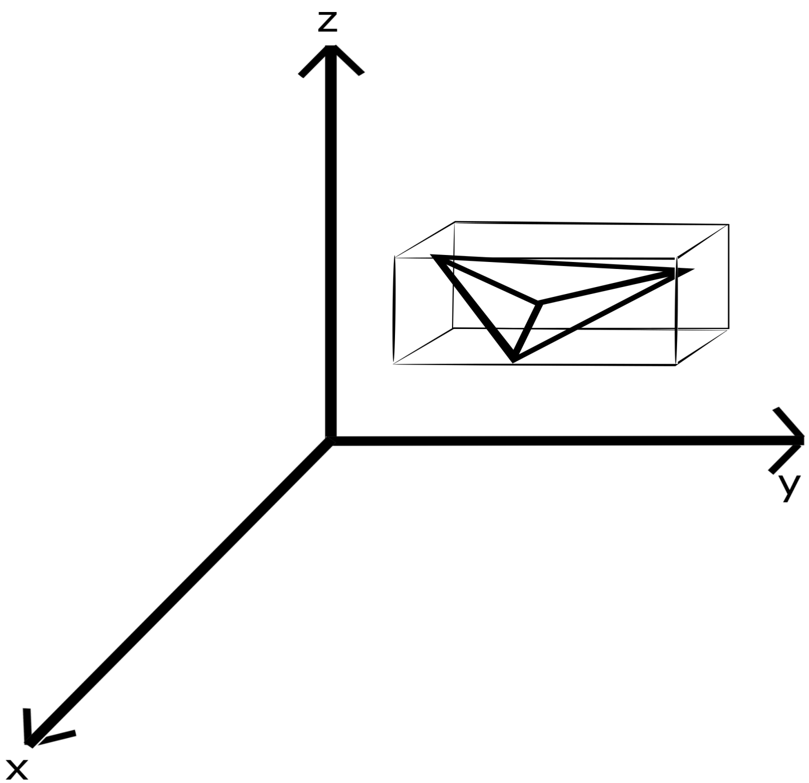
Statistics - Locating Magnetic Nulls
Poincaré Index

The most common method used to locate a magnetic null is by calculating the Poincaré index (PI), a multiple spacecraft method.

- PI = ±1 => Odd number of nulls enclosed
- PI = 0 => Even number of nulls enclosed



Statistics - Locating Magnetic Nulls
Taylor Expansion



Taylor Expansion
(Fu et al., JGR, 2015)

$$r_{null} = r - \nabla \mathbf{B}^{-1}\mathbf{B}.$$

$$\nabla \mathbf{B} = \begin{bmatrix} \frac{\partial B_x}{\partial x} & \frac{\partial B_x}{\partial y} & \frac{\partial B_x}{\partial z} \\ \frac{\partial B_y}{\partial x} & \frac{\partial B_y}{\partial y} & \frac{\partial B_y}{\partial z} \\ \frac{\partial B_z}{\partial x} & \frac{\partial B_z}{\partial y} & \frac{\partial B_z}{\partial z} \end{bmatrix}$$

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Statistics - Conditions

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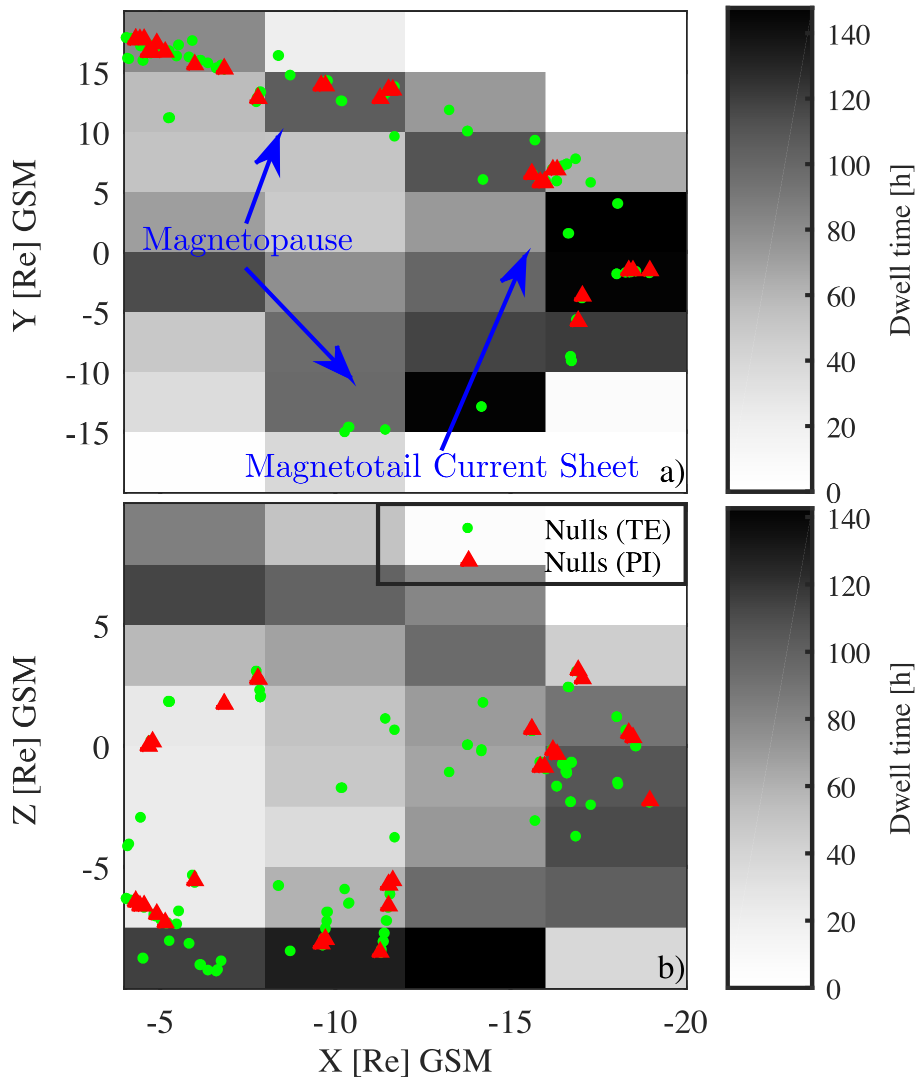
Data: Fluxgate Magnetometer (FGM) from all Cluster spacecraft between July 1, 2003 and January 1, 2004.

Magnetotail: X < -4 RE and |Z|<10 RE.

Constraint: $\left| \frac{\nabla \bullet \mathbf{B}}{\max(|\lambda_i|)} \right| << 1$

- limit chosen as 0.4

Statistics - Results



- More magnetic nulls in the magnetopause current sheet.
- 735 data points of nulls with TE method.
- 84 of those data points correspond with all the nulls found with PI.
- 80% identified as spiral types.

Results - Data Examples

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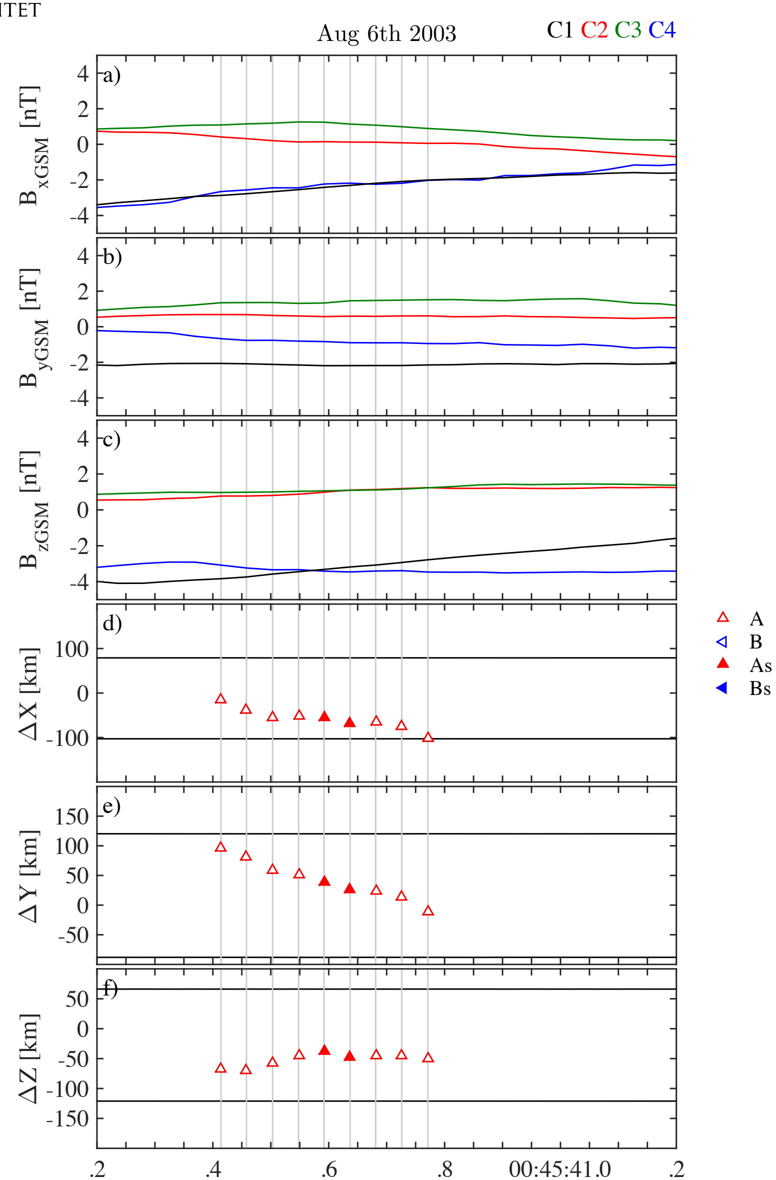
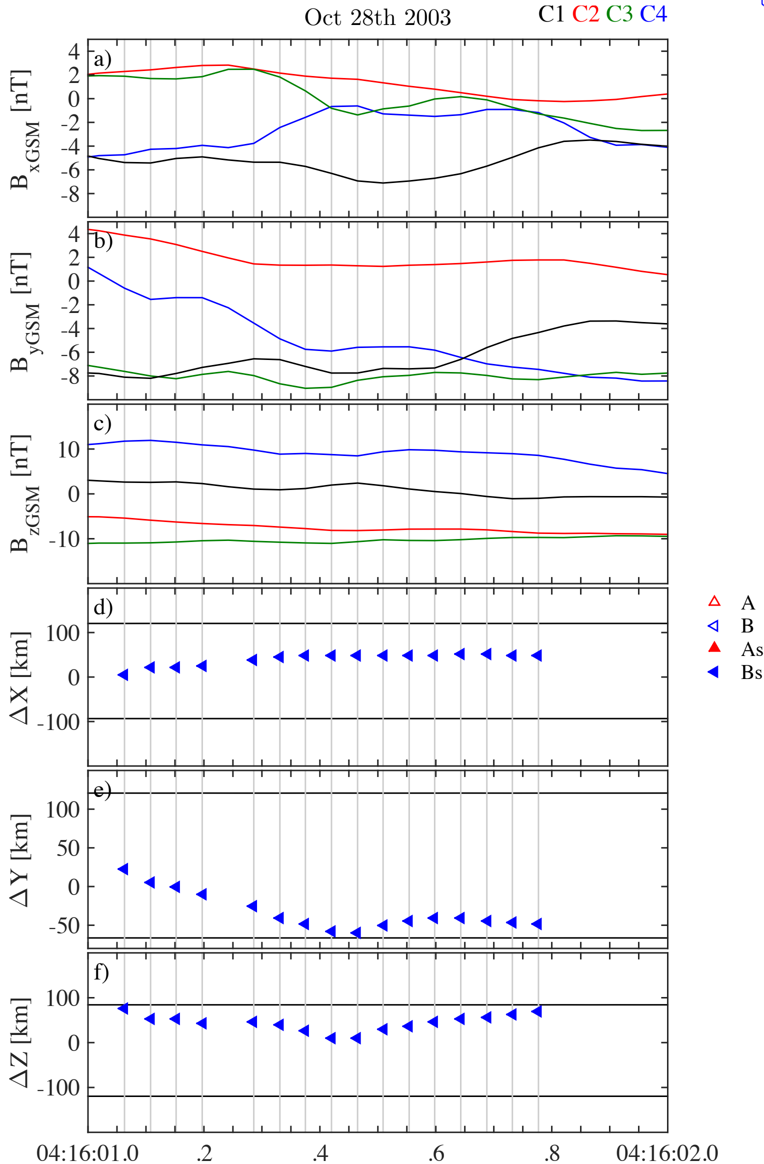


Event I



Event II

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Type identification – Accuracy method (1)

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$\nabla\mathbf{B}$ for each data point rotated into the nulls coordinate system.

$$\nabla\mathbf{B} = \mu_0 s \begin{bmatrix} 1 & \frac{1}{2}(q - j_{II}) & 0 \\ \frac{1}{2}(q + j_{II}) & p & 0 \\ 0 & j_{\perp} & -(p+1) \end{bmatrix}$$

(Parnell et al., PhPl, 1996)

The currents in the tensor refers to the currents parallel and perpendicular to the spine of the null, while j_{th} is a defined threshold current by Parnell et al., PhPl, 1996 and given by:

$$j_{th} = \sqrt{(p-1)^2 + q^2}.$$

Type identification – Accuracy method (2)

Basic concept: compare typical magnetic fluctuations seen in the data with theoretical minimum disturbances capable of altering the type of the null.

- Theoretical minimum disturbance capable of shifting between spiral and non-spiral null type:

$$\delta B_1 = \mu s L(j_{II} - j_{th})$$

- Theoretical minimum disturbance capable of shifting between A-kind (A/As) and B-kind (B/Bs):

$$\delta B_2 = \min(\left| B_{ij} \cdot (B_{ik} \times B_{il}) \right| / \left| (B_{ik} \times B_{il}) \right|)$$

where $B_{ij} = B_j - B_i$ and i,j,k,l are arbitrary permutations of the four spacecraft (1,2,3,4)

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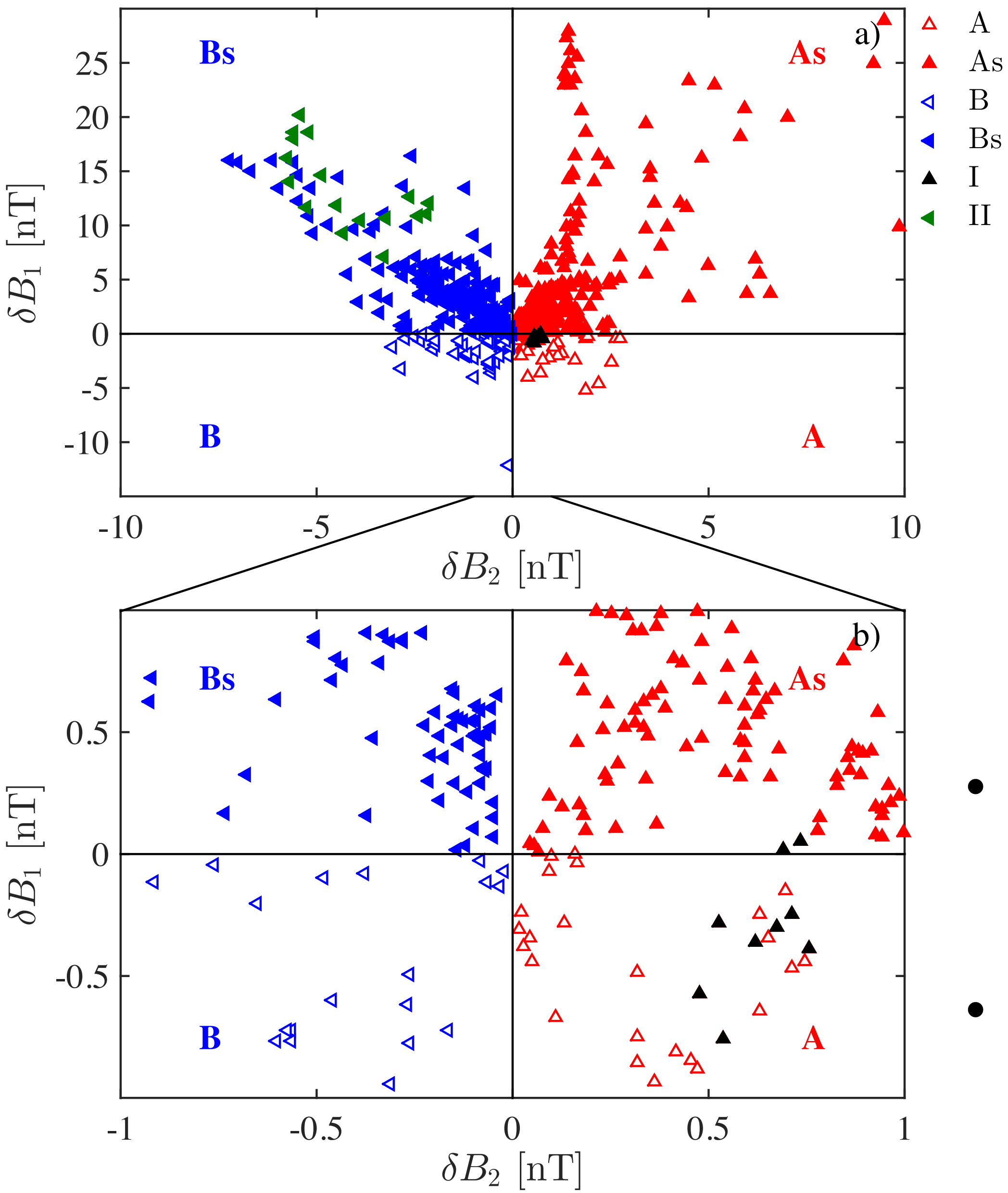
Type identification – Example



Event II:

$\delta B_1 = 7$ nT

$\delta B_2 = 2.2$ nT

Event I:

$\delta B_1 = 0.3$ nT

$\delta B_2 = 0.5$ nT

- Only expect a miss-identification in Event I
- At least 70% of the magnetic nulls have reliable type-identification.

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Conclusions

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- Magnetic nulls were found in both the tail current sheet and in the magnetopause current sheet with about one null per each few current sheet crossings

- The percentage of observed nulls identified as spiral nulls (As and Bs) is close to the percentage from a fully random magnetic field, suggesting that physical processes responsible for the null formation do not favor the formation of particular types of nulls

- The reliability of a null type identification can be estimated by comparing observed local fluctuations of the magnetic field for a particular event with the minimum theoretical disturbances required to alter the null type, δB_1 and δB_2.