Global structure of magnetotail reconnection unveiled by mining spaceborne magnetometer data

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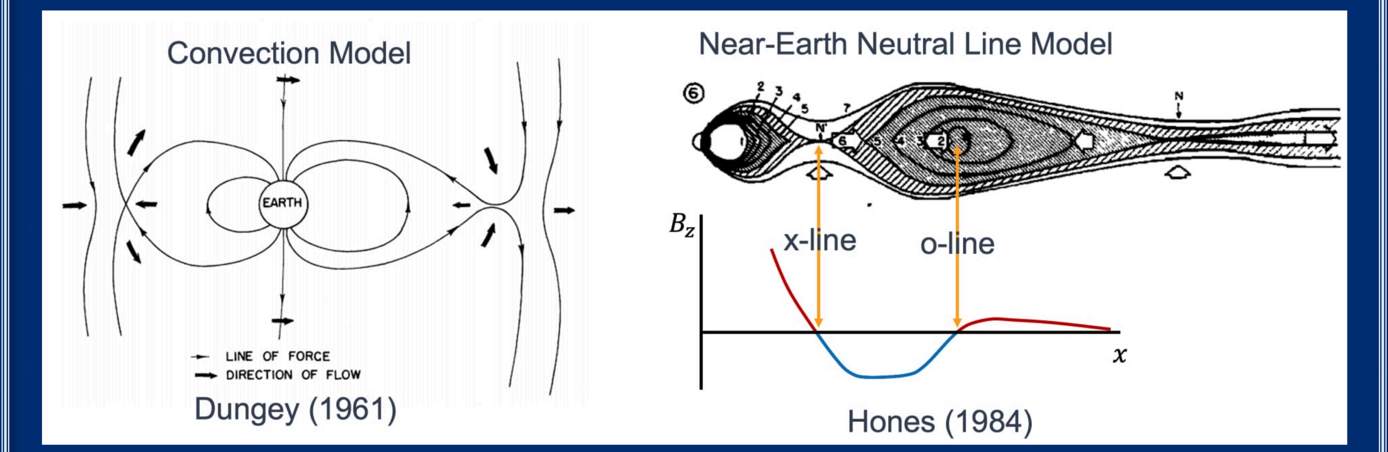
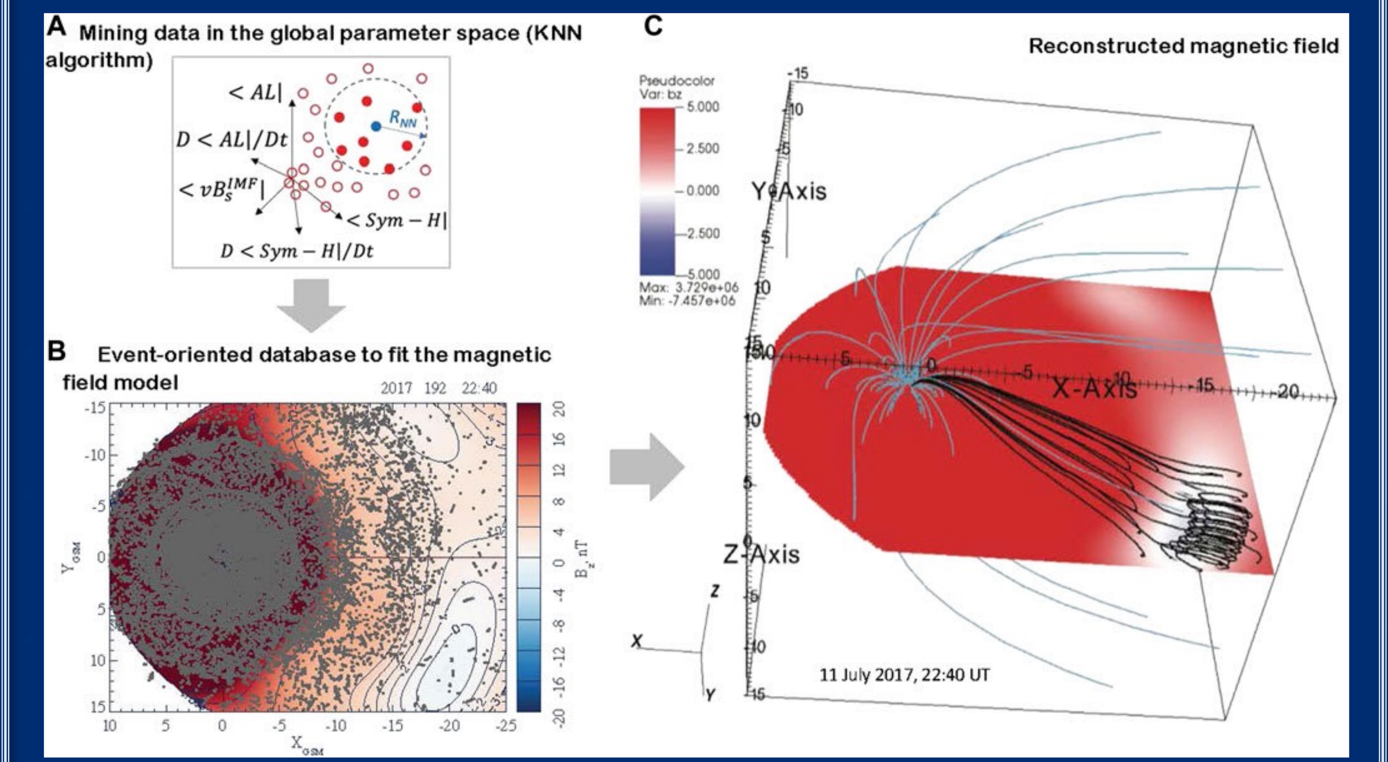
Data Mining (DM) Features

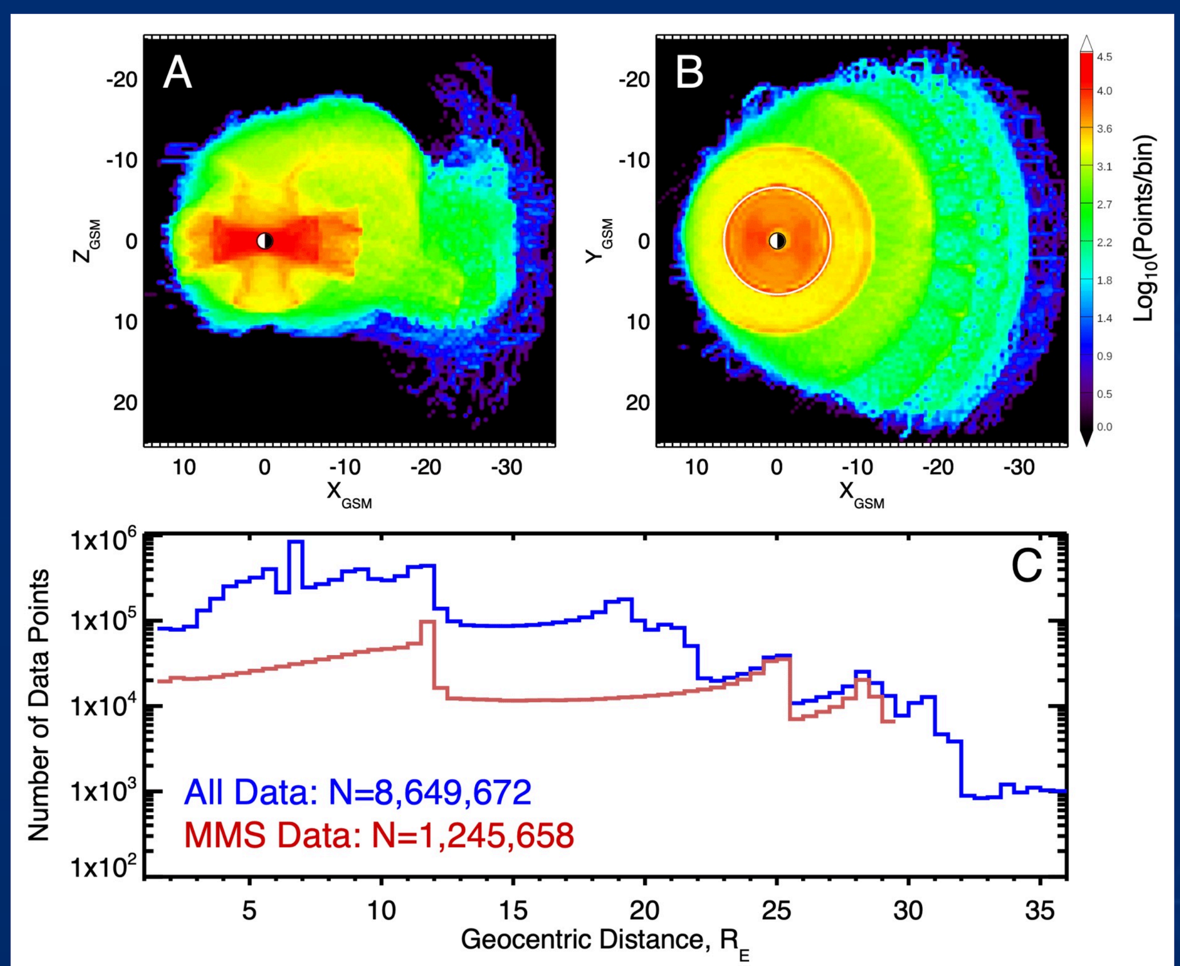
- The **X-line** has long been understood to be a critical component of the magnetospheric magnetic field configuration especially during active times (Dungey, 1961; Hones, 1984)



- **Can DM of space magnetometer measurements reveal the global X-line?**
  - **TS07D Approach**: combine a **flexible empirical description** of the magnetic field with a simple DM algorithm (Tsyganenko & Sitnov, 2007; Sitnov et al., 2008)
  - **SST19** expanded upon this approach to reconstruct **substorms** (Stephens et al., 2019; Sitnov et al., 2019)



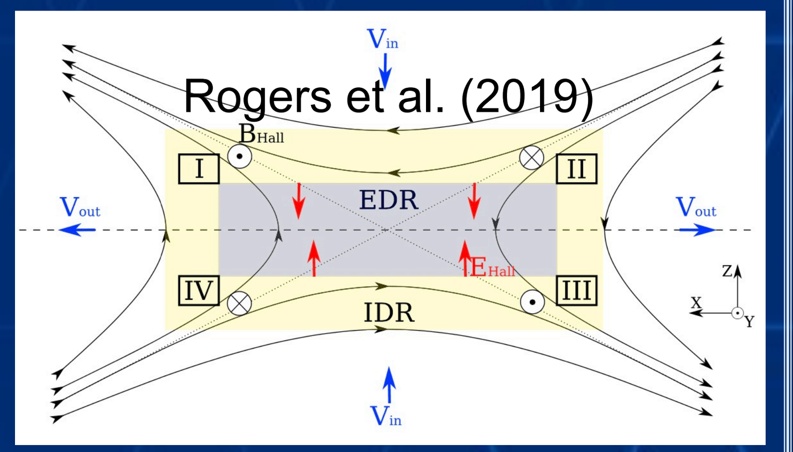
  - The **storm/substorm** state of the magnetosphere is characterized by a 5D state-space consisting of SMR, SML (SuperMAG analogs to $Sym\text{-}H$ and AL), their time derivatives, and vB_s

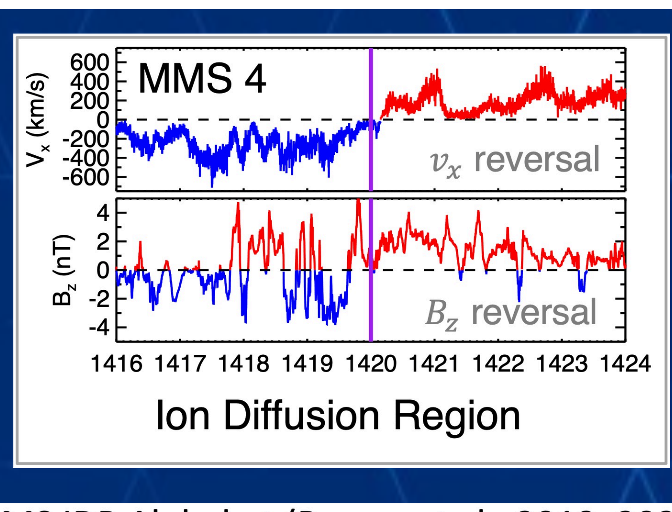


  - Using k-nearest neighbors (Cover & Hart, 1967) the archive is mined to form a virtual constellation of spacecraft from other similar events
  - Archive of data spans 1995–2020 and consists of magnetometer data from Geotail, GOES, Cluster, THEMIS, Van Allen Probes, Imp-8, Polar, and MMS

MMS IDRs

- Resolving the X-line is critical to understanding the global magnetic field morphology
- Using the MMS particle and field data, Rogers, Farrugia, & Torbert (2019) developed an algorithm to locate Ion Diffusion Regions (IDRs)
- As MMS passes through an IDR it can be identified as correlated reversals in the z component of the magnetic field and the x component of the ion velocity along with a strong Hall electric field
- Identified 12 (later expanded to 26) IDRs from 2017–2020: IDR "Alphabet"



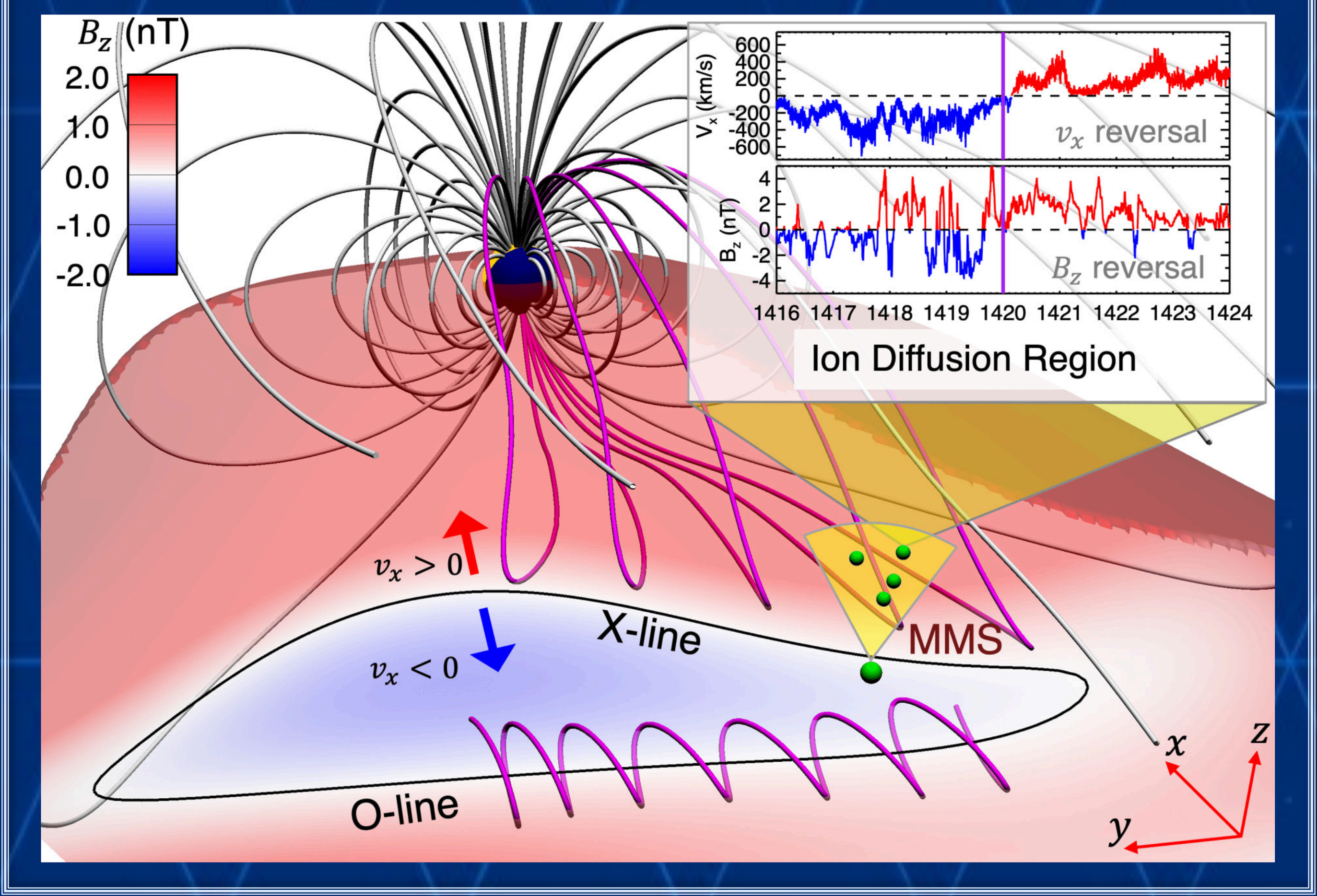


MMS IDR Alphabet (Rogers et al., 2019, 2021)

Event	Date/time	Event	Data/time
A	2017-05-28/03:57	N	2018-08-26/06:38
B	2017-07-03/05:26	O	2018-08-27/11:39
C	2017-07-06/15:34	P	2018-08-27/12:14
D	2017-07-06/15:45	Q	2018-09-10/17:14
E	2017-07-11/22:33	R	2018-09-10/23:57
F	2017-07-17/07:48	S	2019-07-25/21:40
G	2017-07-26/00:02	T	2019-08-31/12:01
H	2017-07-26/07:00	U	2019-09-06/04:38
I	2017-07-26/07:27	V	2020-08-02/16:58
J	2017-08-06/05:13	W	2020-08-02/17:09
K	2017-08-07/15:37	X	2020-08-03/01:04
L	2017-08-23/17:53	Y	2020-08-05/14:19
M	2018-08-15/11:57	Z	2020-08-29/09:56

Conclusions

- **DM** based empirical reconstructions of the magnetic field pinpoint the **global** configuration of X- and O-lines as **confirmed by MMS** observations
  - **23** of the **26** IDR alphabet events are well reconstructed or partially reconstructed!
  - **16** of those **23** IDRs are "Hits" within $\lesssim 2\,R_E$ of the $B_z = 0$ contour, 7 more are "Near Hits" within $\lesssim 2\,R_E$ of the $B_z = 2$ nT contour
  - This is remarkable given that only **~0.03%** of the data points are from the **event of interest**, with the other **~99.97%** are from **other events** identified by DM
- DM **expands** the **Multiscale aspect of the MMS** mission to include **global scales**

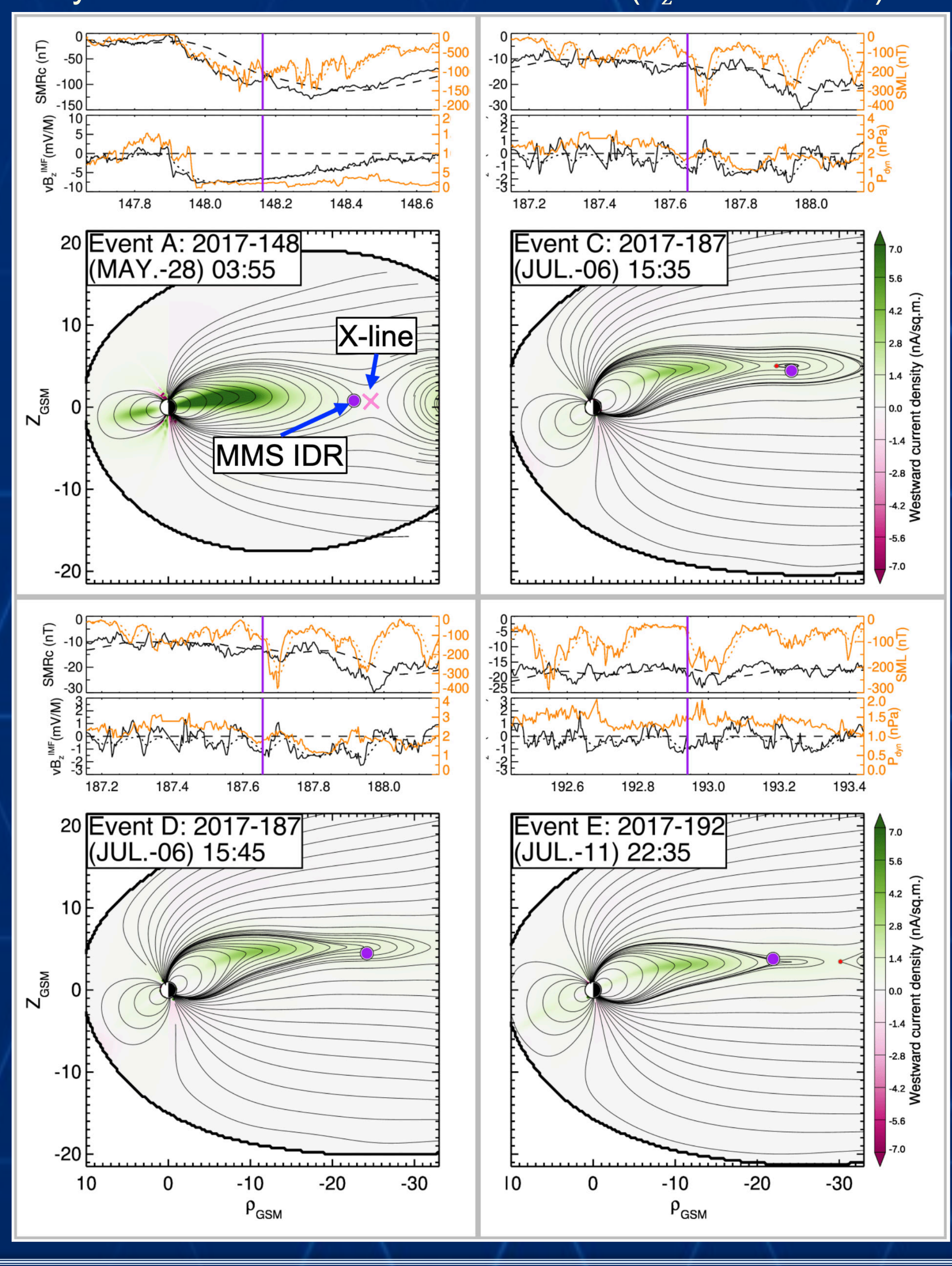


Alphabet of IDR Reconstructions

- SST19 was upgraded to facilitate modeling these events
  - The $Sym\text{-}H$ and AL indices were replaced by their SuperMAG analogs (SMR and SML)
  - The MMS dataset was expanded from 1 to 3 tail seasons (2015–2020)
  - A variable TCS is used assuming its thickness is determined **ion Speiser orbits**

$$D_{TCS}(\rho) = \left[\alpha e^{-\beta\rho} + \frac{1}{D_0}\right]^{-1}$$

- Equatorial slices show that MMS IDR locations (purple circles) closely match the modeled X- or O-lines ($B_z = 0$ contour)



- Meridional slices confirm $B_z = 0$ contours indeed represent X- and O-lines