EMHD GRAD–SHAFRANOV RECONSTRUCTION OF THE ELECTRON DIFFUSION REGION WITHIN A FLUX ROPE

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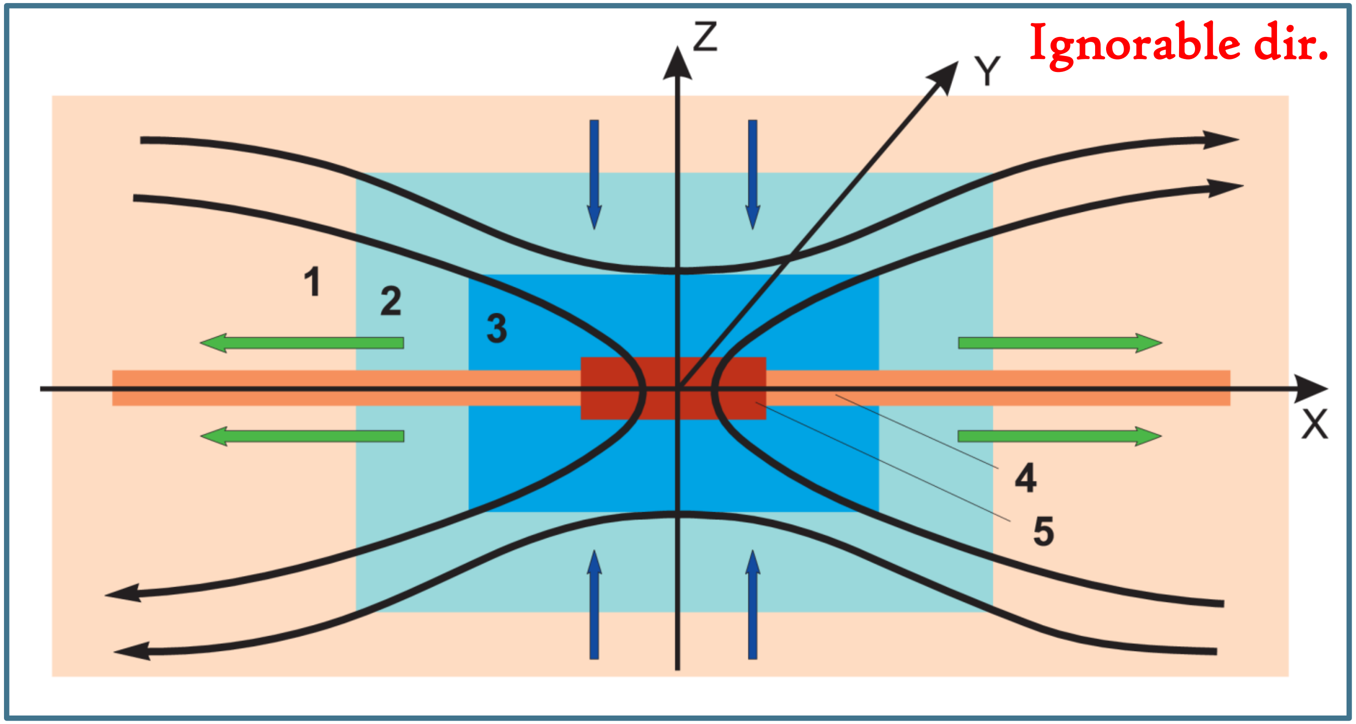
EMHD RECONSTRUCTION MODEL

Electron MHD model of the incompressible 2-D steady-state magnetic reconnection kernel zone (EDR) is introduced in the study of Korovinskiy et al. (2021, JGR, 126).



Sketch of the reconnection region

Here, numbers 1, 2, and 3 mark MHD, HMHD, and EMHD regions, respectively, and 4 and 5 point at external and internal segments of the electron diffusion region (EDR), respectively.

Unlike the previous models of that kind (e.g., Sonnerup et al., 2016, JGR, 121), our model is designed to operate with the MMS mission data, using all available records (two probes at least are required) to set up the calculations.

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RECONSTRUCTION MODEL: EQUATIONS

1. The set of steady-state 2-D EMHD equations (Maxwell + Ohm's law) is addressed in dimensionless units and reduced to two equations: equation for the magnetic potential A of the in-plane magnetic field, and equation for the out-of-plane magnetic field B_y. Solutions for all other quantities are obtained from these two ones. At the same time, the pair $(A,\ B_y)$ can be considered as a pair of independent variables instead of the in-plane cartesian coordinates $(x,\ z)$.
2. The usage of the multi-probe dataset brings two essential advantages:
   a) The electron inertia term in the Ohm's law becomes computable;
   b) The artificial closure for the electron pressure tensor becomes redundant.

This way we arrive at two equations,

I. $$\Delta A = nV_0(A) - \frac{1}{n}\frac{dQ}{dA}\tilde{B}_y$$ ⟵ The Grad–Shafranov Eq. + small extra term, omitted in the current study

II. $$\Delta \tilde{B}_y = Q(A) + \frac{1}{n}\frac{dn}{dA}\left(\nabla A \cdot \nabla \tilde{B}_y\right)$$

Here, Δ stands for the in-plane Laplace operator, $\tilde{B}_y = B_y - B_g$ is the non-uniform Hall magnetic field, B_g is the uniform guide field, and functions V_0 (major part of the electron out-of-plane velocity) and Q are derived from BC. The last term of Eq. II represents the model extension for compressible plasmas (external EDR).

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EVENT OF 2018/09/08

We consider an event of MMS encounter of electron diffusion region near the center of a flux-rope type dipolarization front on September 9, 2018 at around 14:51:30 UT at (x,y,z) = (−13.4, 5.6, 0.84) R_E^{GSE} reported by Marshall et al. (2020, JGR, 125).

We performed the reconstruction of the magnetic potential in LMN coordinate system specified by three orts

$\mathbf{e}_L = [-0.1456, +0.2985, +0.9432], \sim +Z_{GSE}$

$\mathbf{e}_M = [+0.0876, +0.9535, -0.2882], \sim +Y_{GSE}$

$\mathbf{e}_N = [-0.9854, +0.0407, -0.1650], \sim -X_{GSE}$

differing from the Marshall's ones by the opposite orientation of the M and N orts.

The structure velocity in LMN is estimated by using the timing method (Russel et al., 1983, JGR, 88) as $\mathbf{V}_0 = [+117, +234, -216]$ km/s.

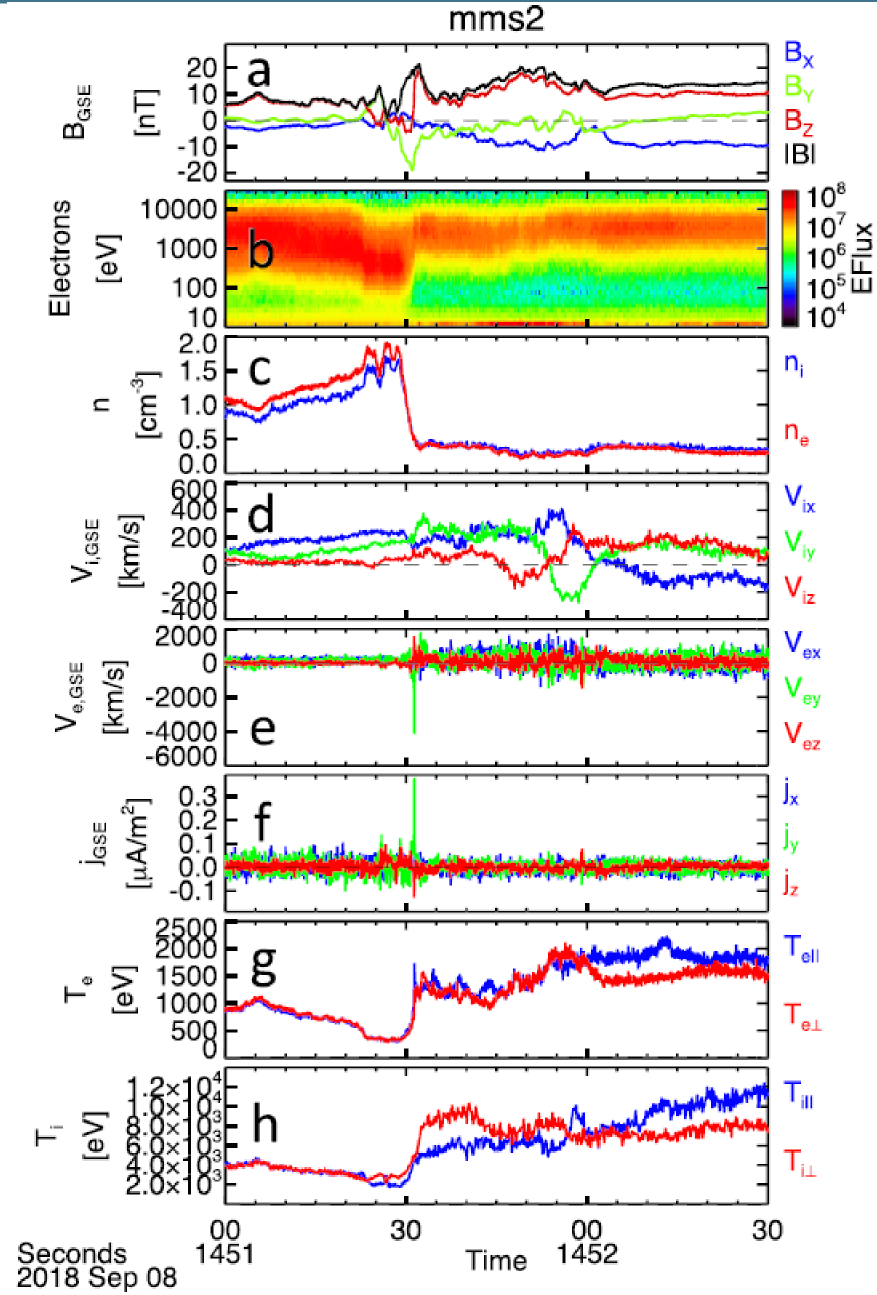


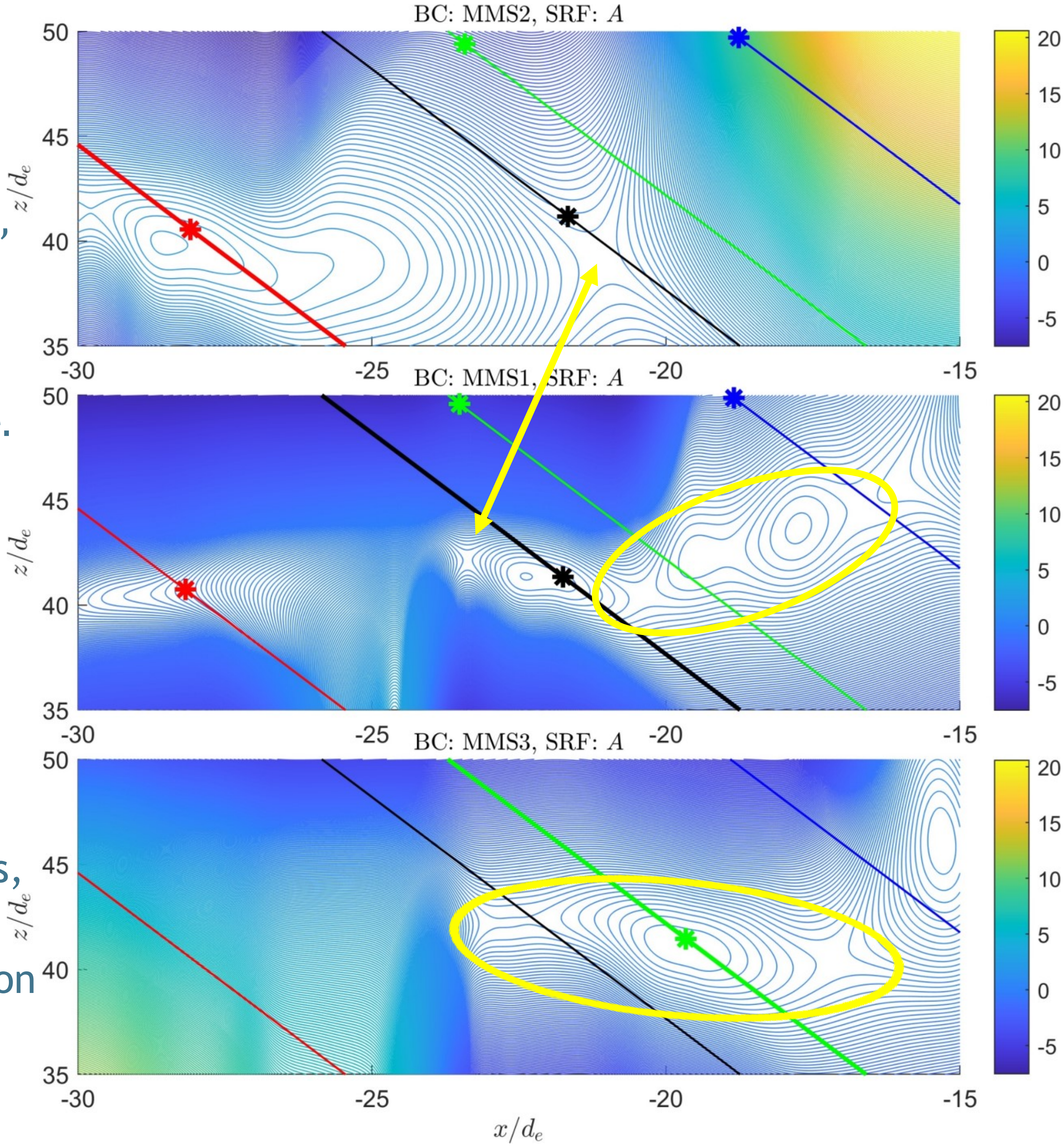
Fig. 1 from Marshall et al. (2020)

RESULTS

We study 1.5 s time interval, 14:51:30.25—31.75 UT.

MMS1 – black, MMS2 – red, MMS3 – green, MMS4 – blue.

$d_e = 5.3\ km.\ XZ \leftrightarrow LN$



CONCLUSIONS

1. MMS1 passes through the very center of EDR, X-line structure is clearly seen.
2. More complex structure, exhibiting the chain of X-lines, may be in esse, but
3. The structure time evolution restricts the reconstruction model efficiency.