ÖAW IWF

Forum on Cross-scale Measurements of Space Plasmas to Explore Magnetic Reconnection, 5-6 September 2019, Beijing

MULTI-SCALE PROCESS OF MAGNETOTAIL RECONNECTION AND LIMITATIONS OF CLUSTER/MMS 4-POINT MEASUREMENTS

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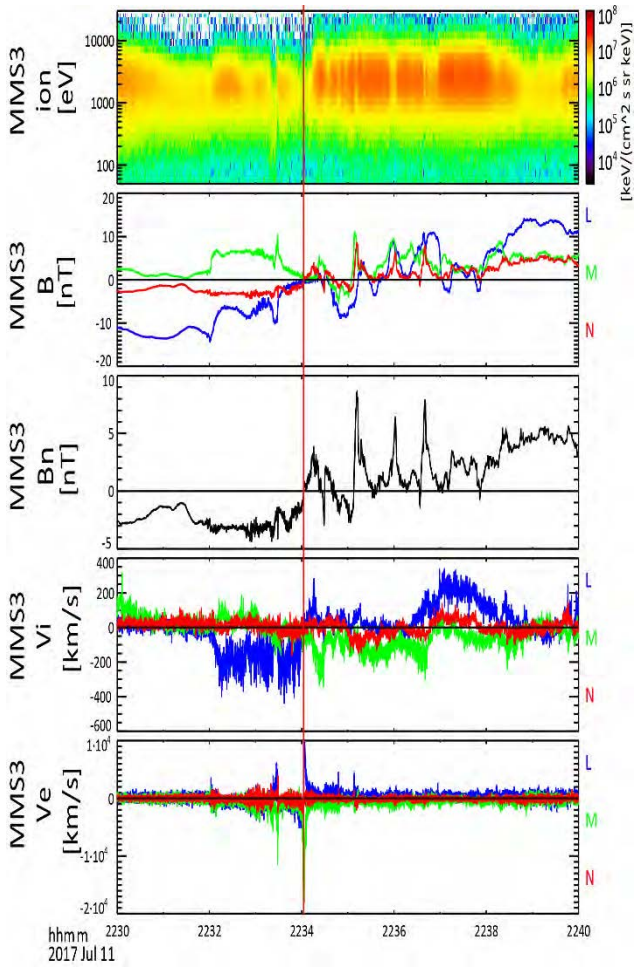
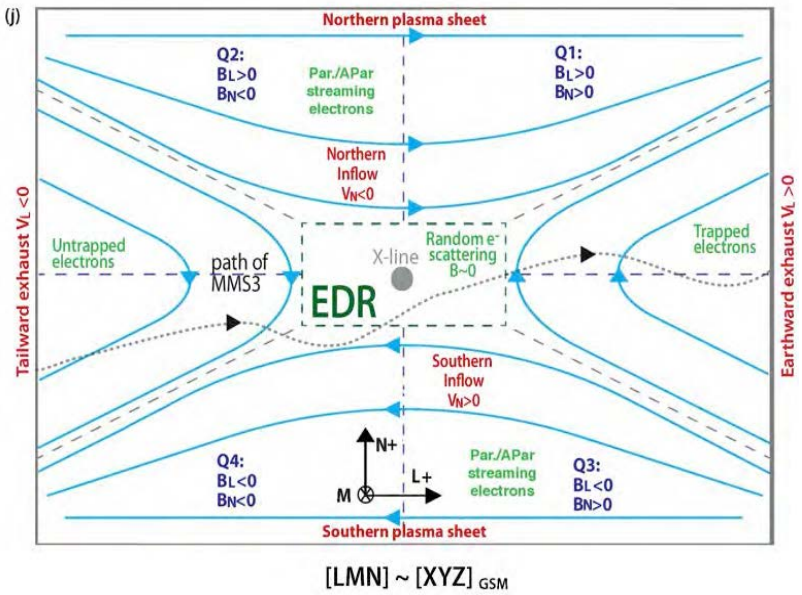
ALMOST 2D CURRENT SHEET RECONNECTION

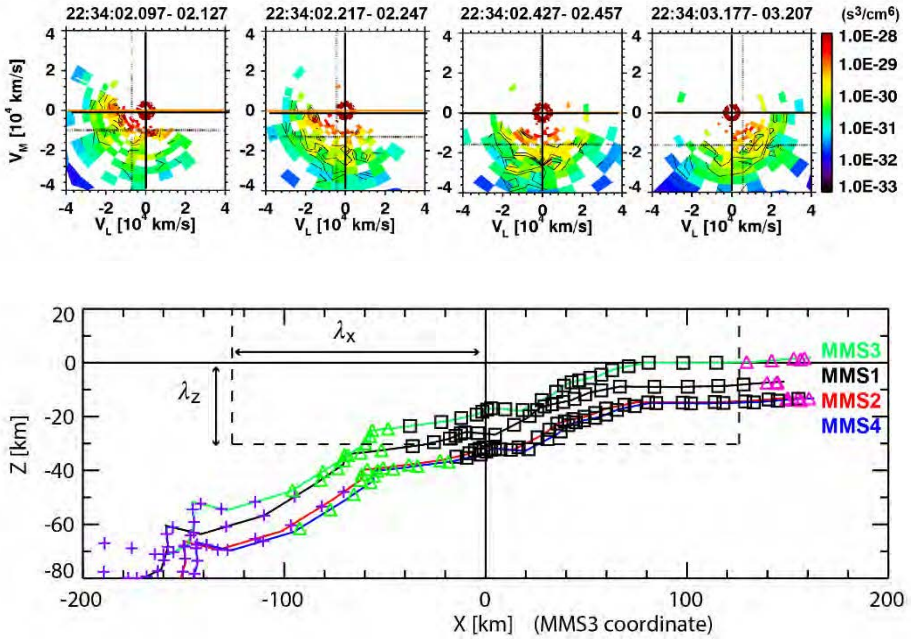
Guide field < 0.03, MMS 25 RE downtail near midnight





(Torbert et al., 2018)

EDR: electron diffusion region (~1 s)

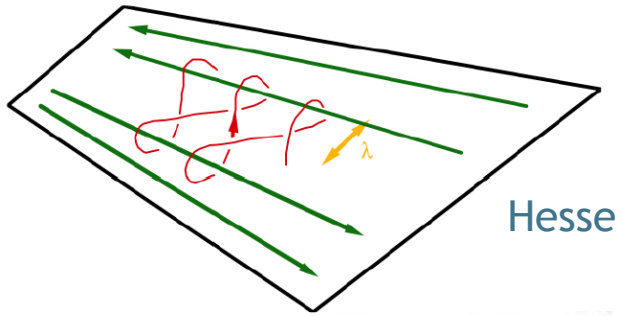


(Nakamura et al., 2019)

Meandering electrons accelerated along dawn-dusk reconnection electric field detected In EDR

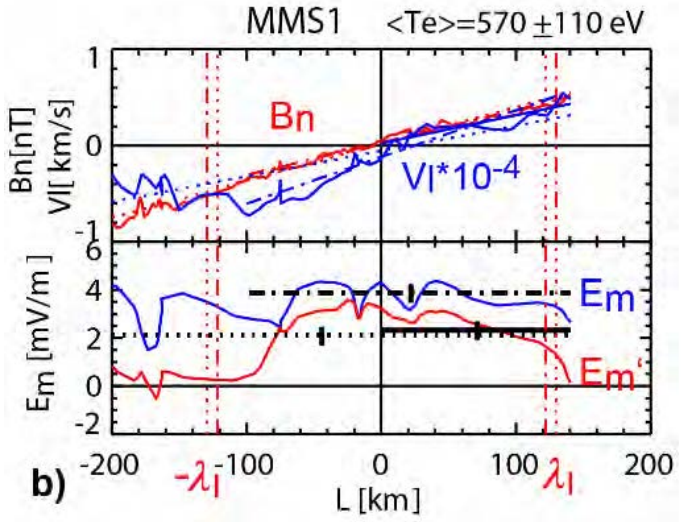
EDR SCALE & RECONNECTION ELECTRIC FIELD

Theory: EDR scale ~bounce width in reconnecton magnetic field [Hesse et al., 1999]

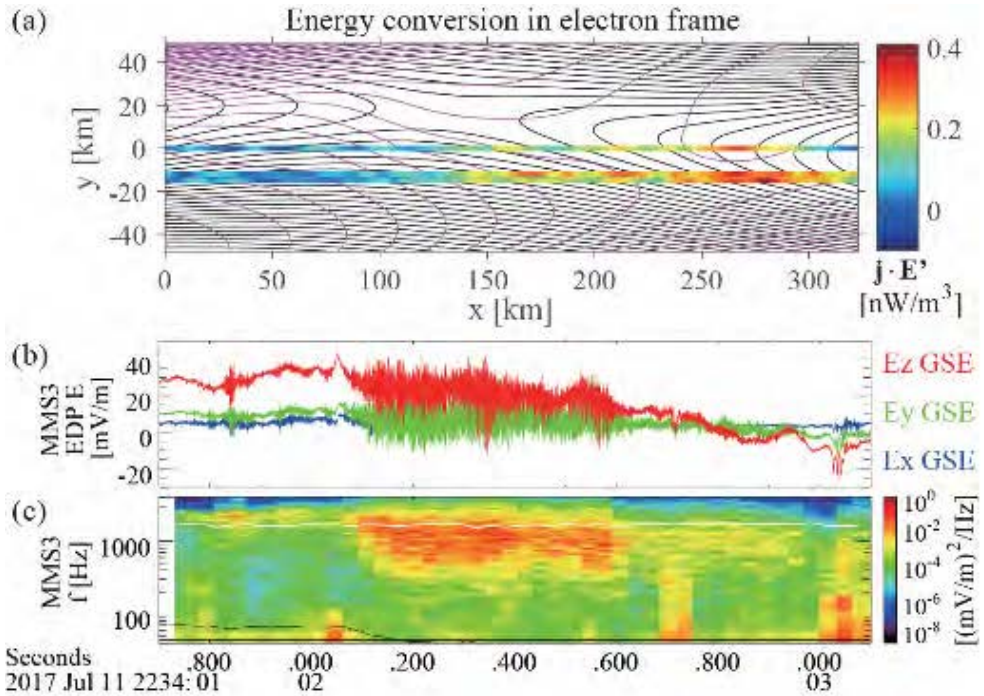


Hesse et al. [2011}

Em_theory consistent with observation



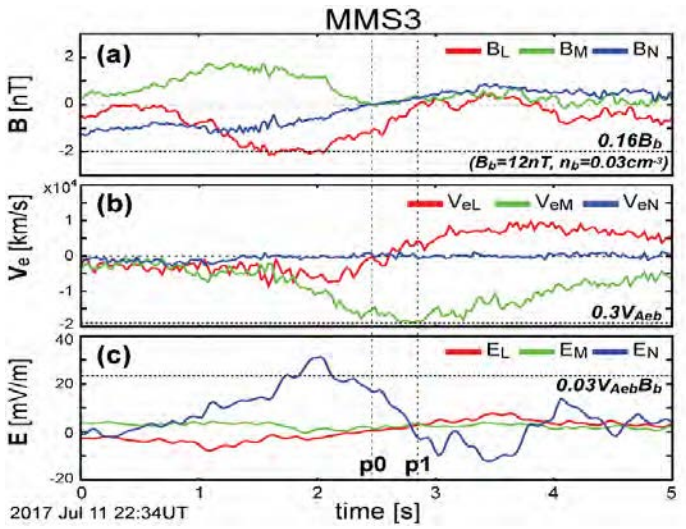
[Nakamura et al., 2019]

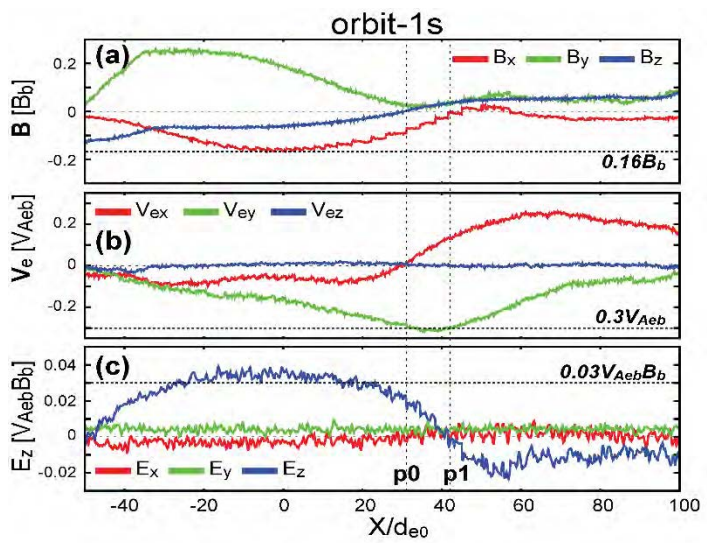


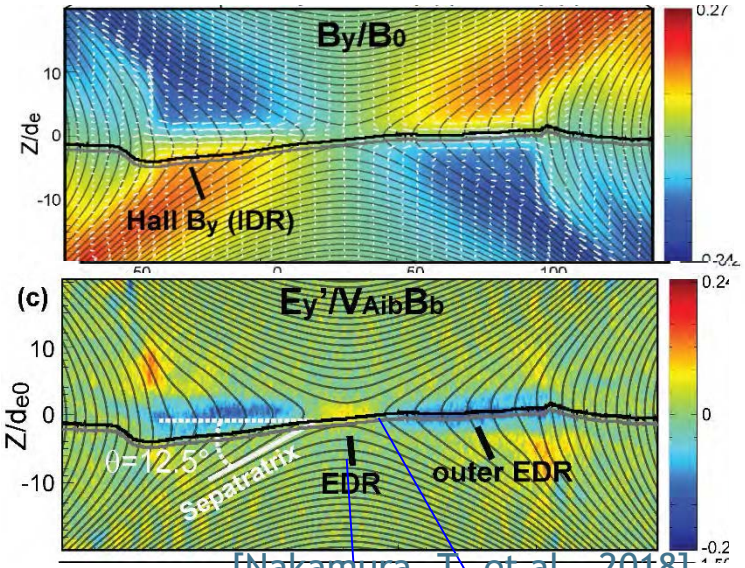
[Hasegawa et al., 2019]

JE'>0 peaks in flow reversal region
dissipation not due to high-freq. waves, but in EDR

EDR OBSERVATION V.S. SIMULATION



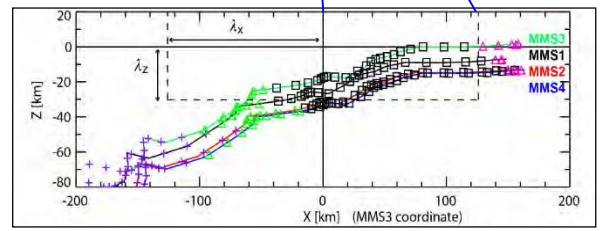




[Nakamura, T, et al., 2018]

→ Remarkable resemblance in B, Ve, E profile

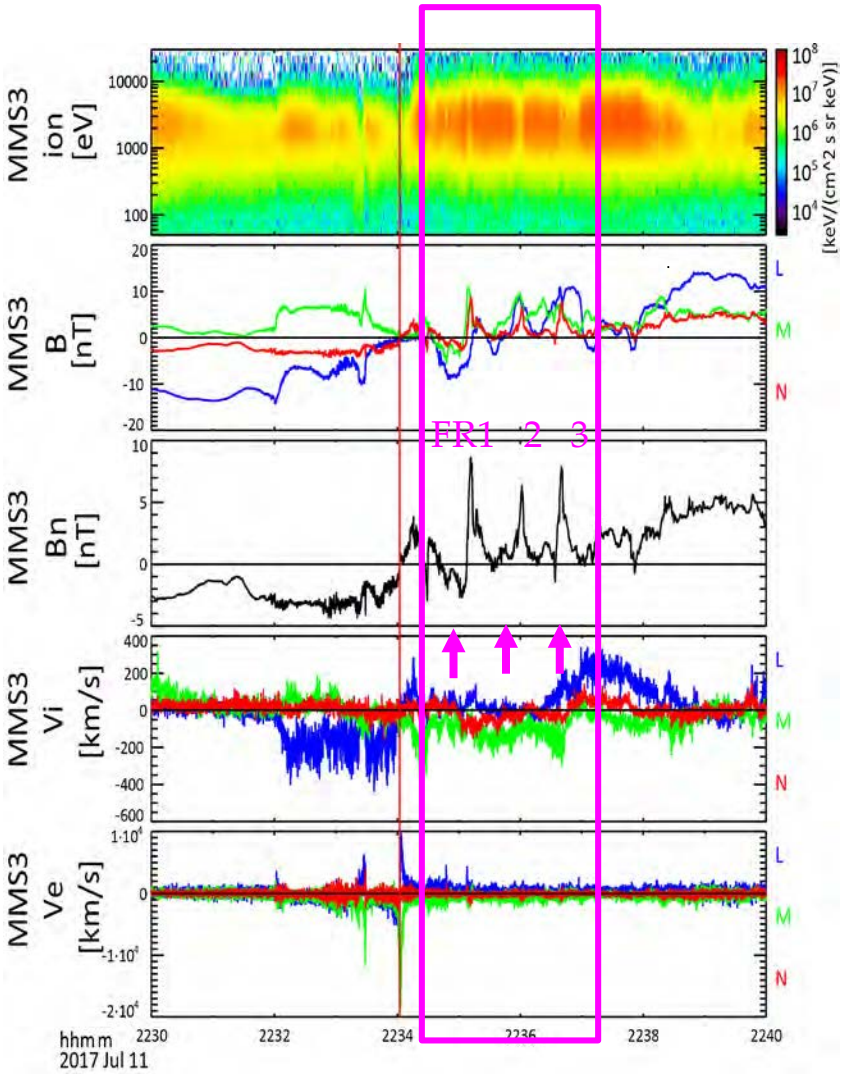
→ Reconnection electric field Ey 2.5 ~ 4 mV/m [Genestreti et al., 2018], consistent with the simulation [Nakamura, T., et al. 2018]



[Nakamura, R, et al., 2019]

- Inner EDR scale across CS ΔN: 30 ± 7 km
  ~ gyro-scale of V_{Te} around B_{lo} (Hesse et al., 1999) λz = 31km ~ 1 de
  → consistent with simulations [Shay et al.,2007; T.Nakamura et al., 2016; Le et al., 2016]
- Inner EDR scale ΔL: 125 ± 23 km: λx = 120-160 km~ 4-5 de ~ 0.1 di
  → 3 - 6 times smaller than simulations [Goldman et al. 2011; T. Nakamura et al.,2016,2018]

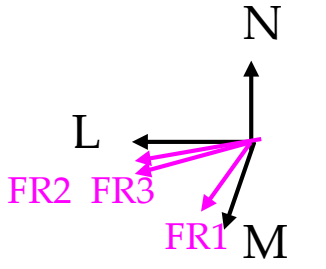
3D STRUCTURES NEAR "2D" RECONNECTION X-LINE: FLUX ROPES



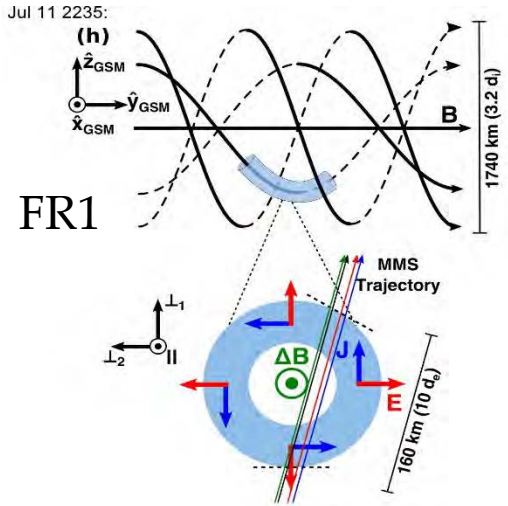
Multiple ion-scale fluxropes with different core field tilt

		core field angle to: L	M	N
FR1	22:35:07.0 – 22:35:11.0	73.4°	22.2°	104.3°
FR2	22:35:58.0 – 22:36:03.0	25.9°	64.2°	88.6°
FR3	22:36:33.0 – 22:36:43.0	32.1°	58.3°	85.6°

(Teh et al., 2018)



Electron vortex structure with intense E

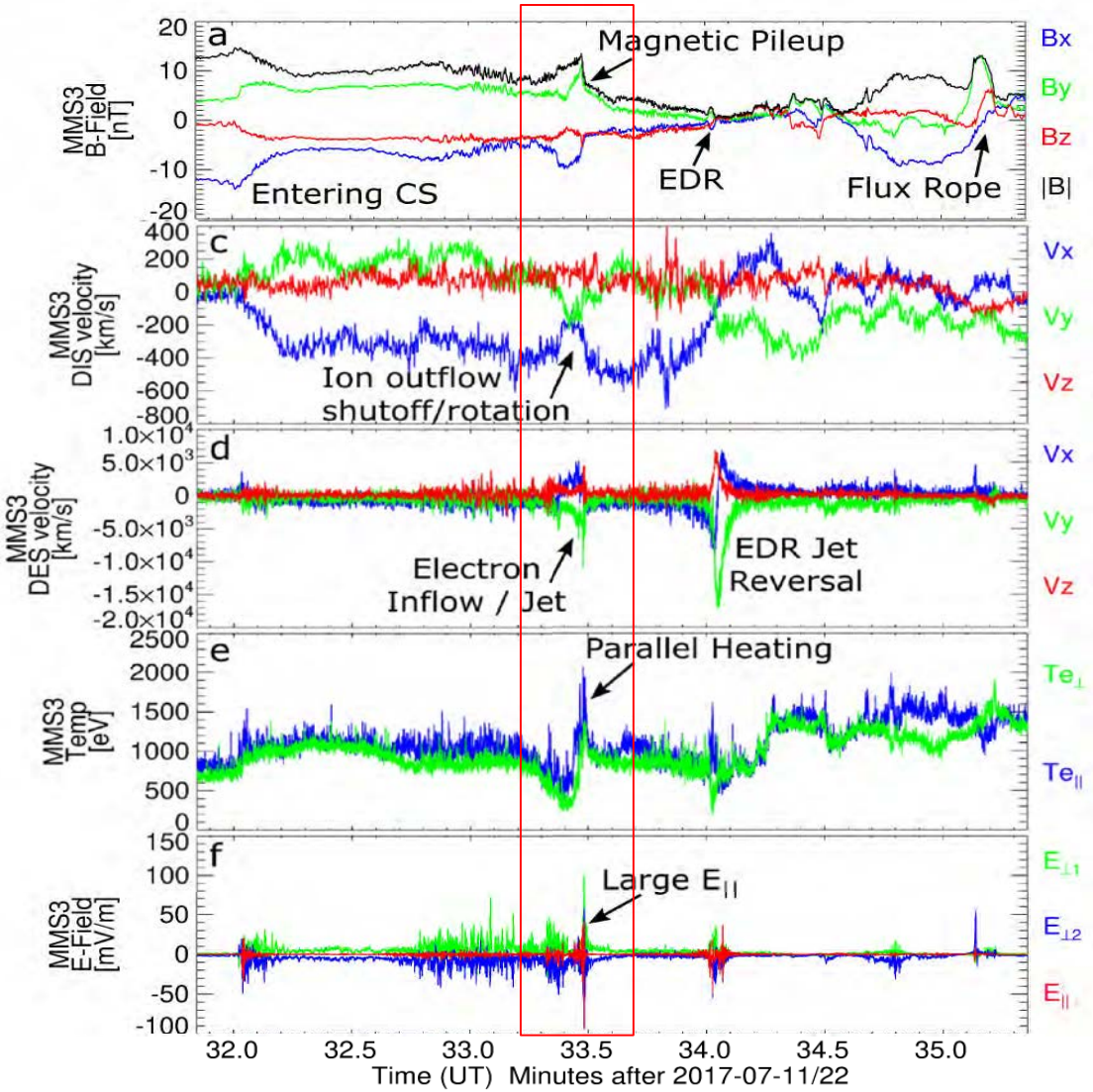


(Stawartz et al., 2018)

3D structures after„2D" reconnection X-line event

E-SCALE INTERACTION AT SEPARATRIX REGION

- E//, Te// maximum at separatrix region where Ve reverse/deflect
- Heating associated with Ve- inflow (not outflow from EDR) is deflected/braked at flux pileup region
- Simultaneous monitoring of EDR and outflow/inflow region important



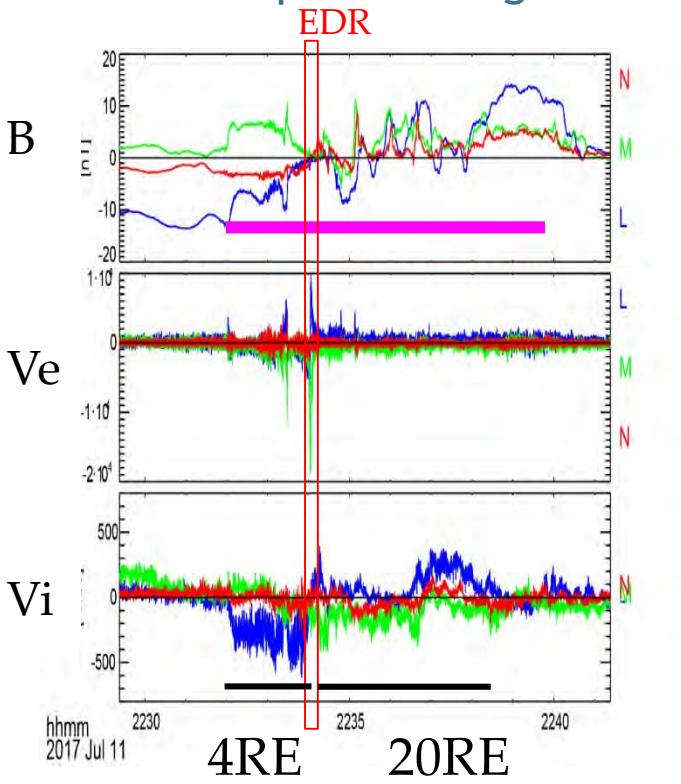
(Holmes et al., 2019)

CONTEXT DATA IMPORTANT

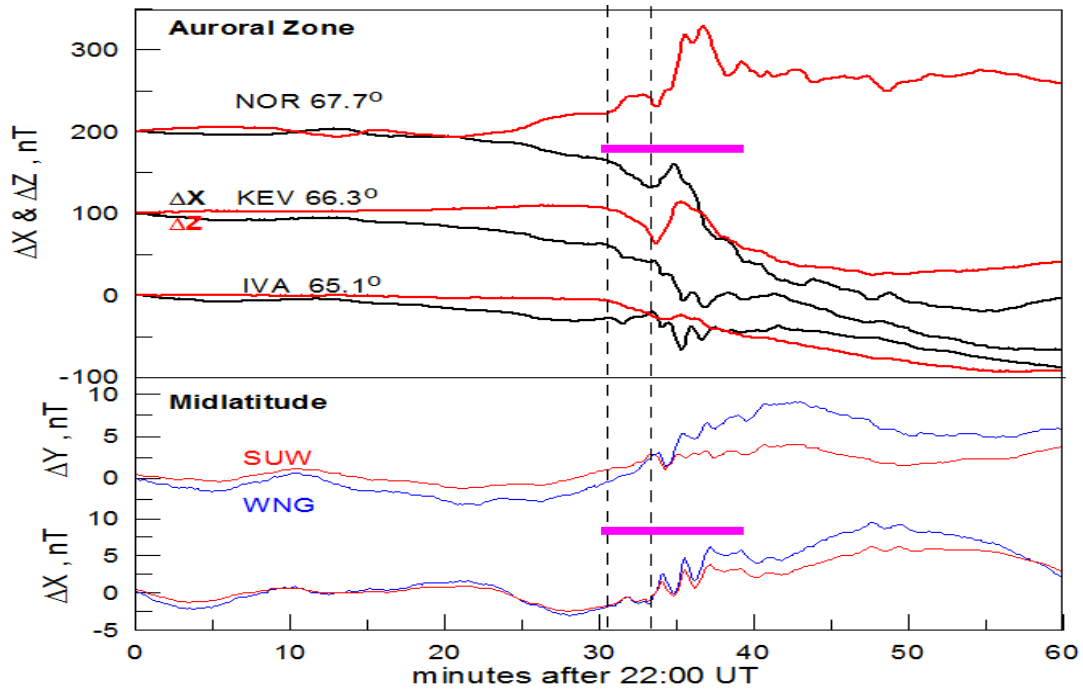
X-line, flux ropes events with current sheet flapping

→ multiple ionospheric current enhancements

→ temporal changes in reconnection rates in min scale



Ion jet scale, if X-line propagate tailward with 200 km/s



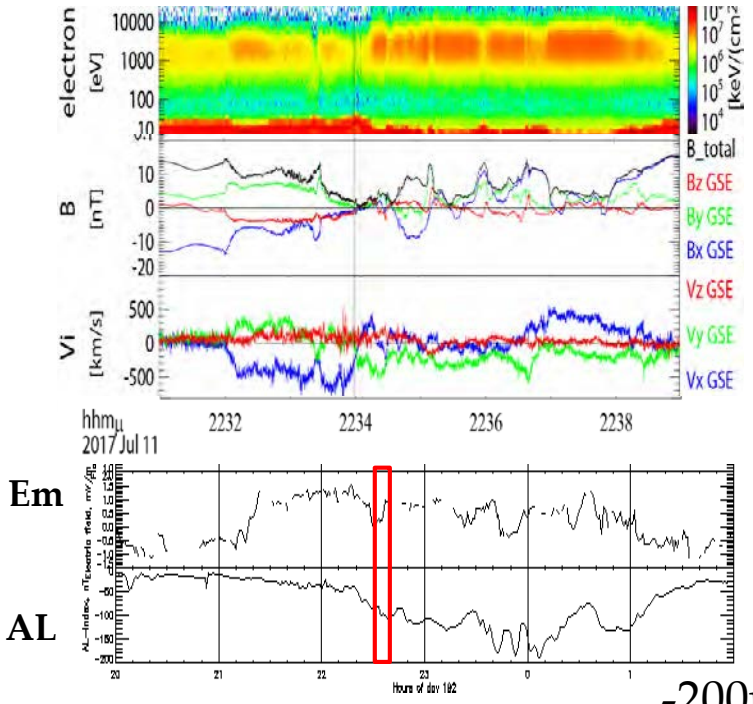
.. weak electrojet (~150 nT)

~ oscillations with similar time-scale

RECONNECTION FEATURES DIFFERENT

2D laminar reconnection (weak heating)

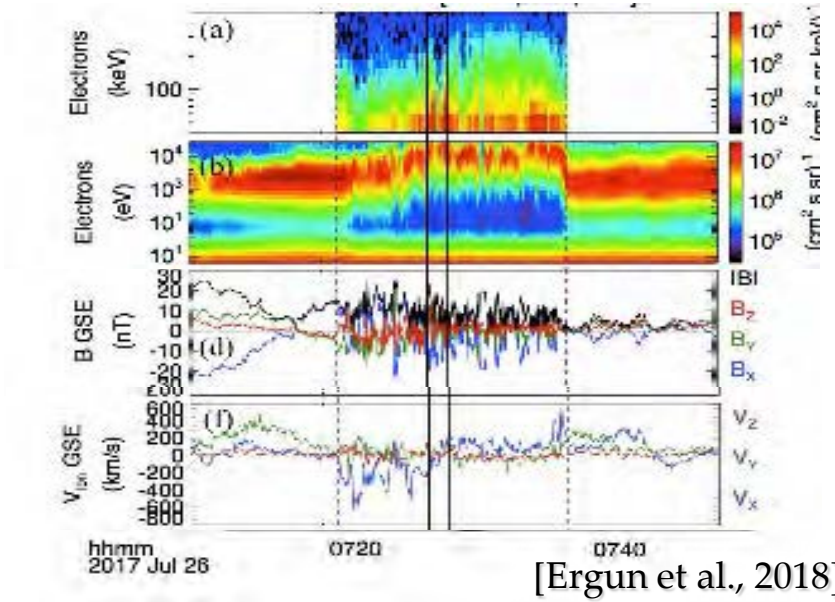
Em: ~1mV/m, Bz: -2~-3 nT, AL-200



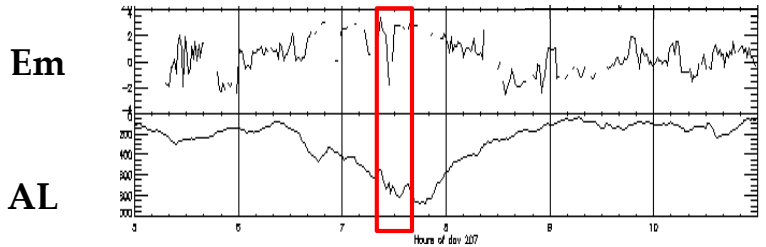
-200nT

Turbulent reconnection (strong heating)

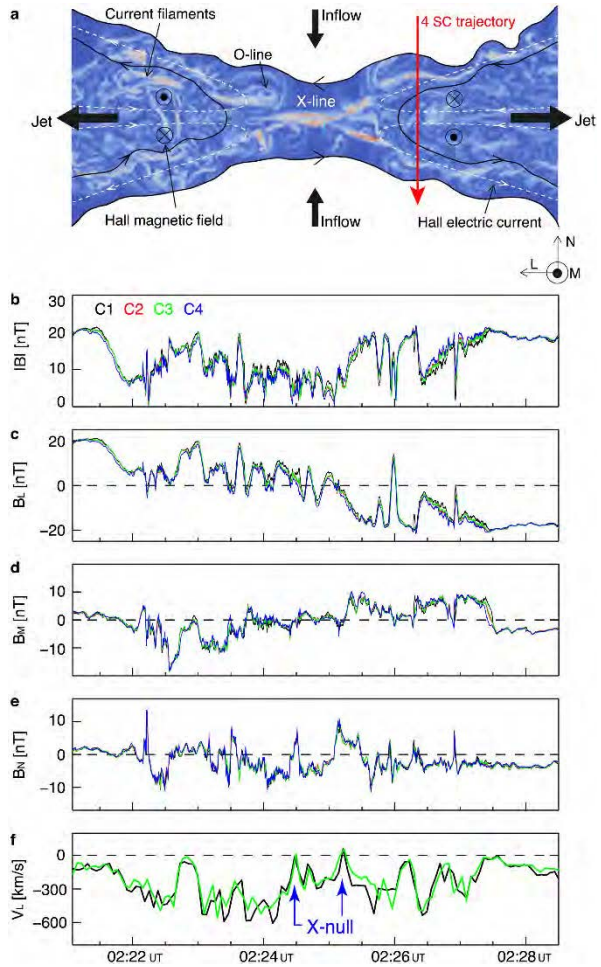
Em: ~2mV/m, Bz: -2~-3 nT, AL -1000



[Ergun et al., 2018]



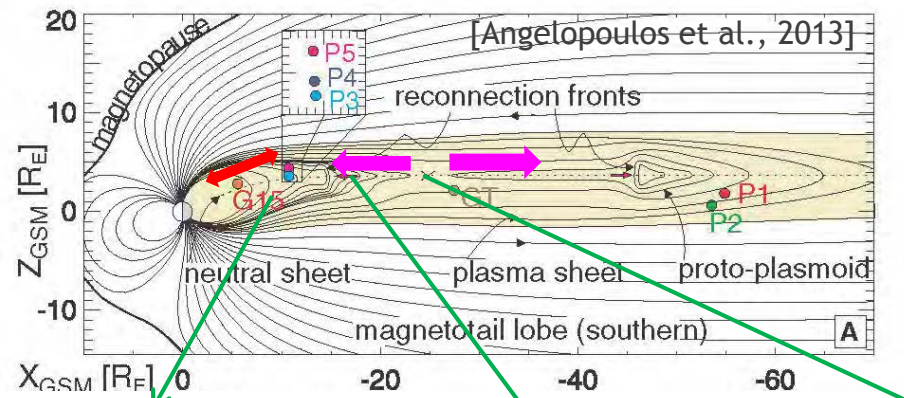
-1000nT

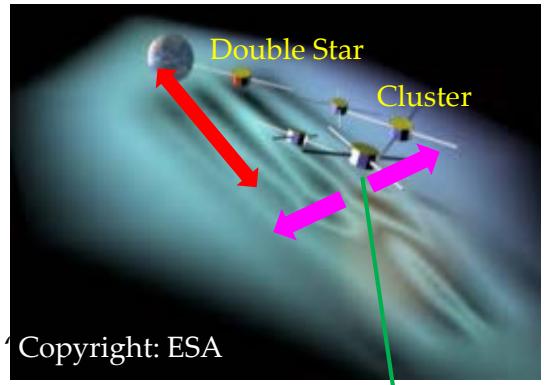


[Fue et al., 2017]

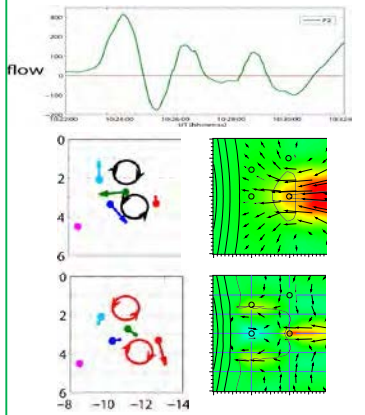
MESOSCALE DRIVERS IN MAGNETOTAIL

Propagation “along” as well as “across” the tail



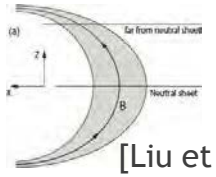


flow braking/bouncing

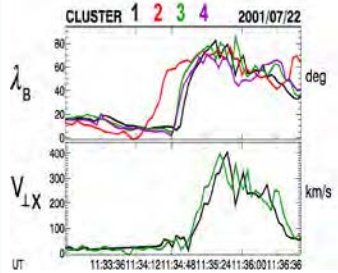


[Panov et al., 2010; Birn et al.,2011]

dipolarization front (dipolar flux bundle)

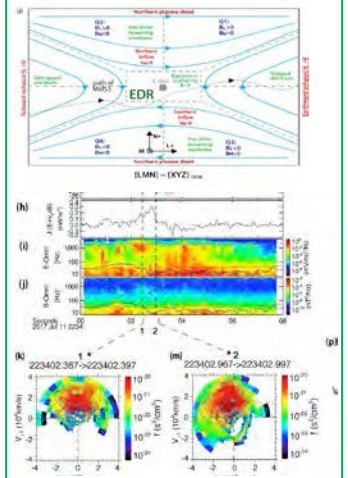


[Liu et al., 2013]



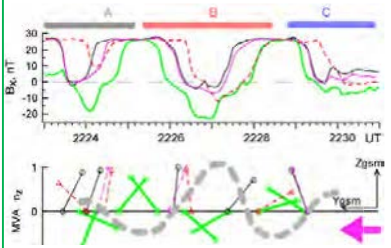
[Nakamura et al., 2002]

magnetic reconnection

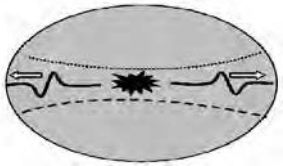


[Torbert et al., 2018]

current sheet flapping



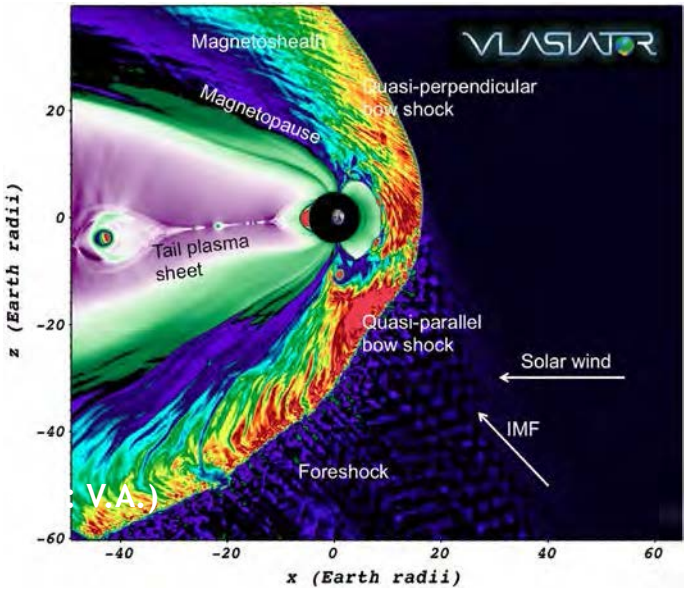
[Sergeev et al., 2003]



[Sergeev et al., 2004]

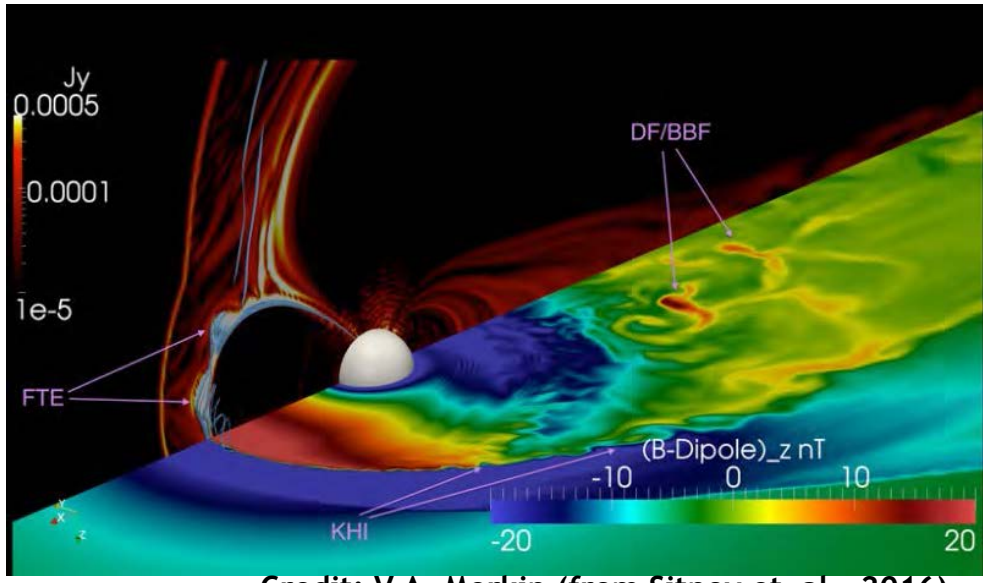
MODELLING CHALLENGE FOR UNDERSTANDING OF SOLAR WIND-MAGNETOSPHERE COUPLING

2D global hybrid Vlasov



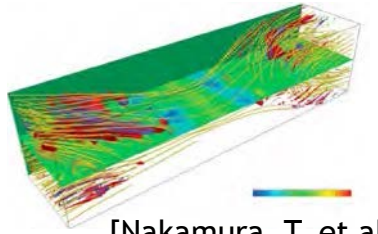
[Palmroth et al., 2018]

3D global MHD



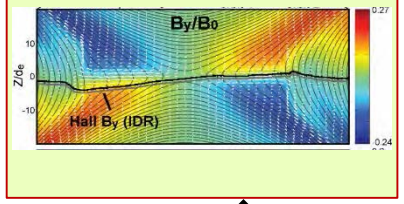
Credit: V.A. Merkin (from Sitnov et al., 2016)

Full kinetic local 3D: low mi/me



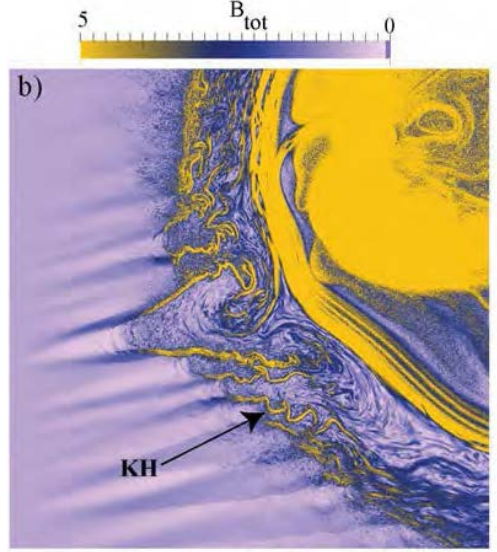
[Nakamura, T. et al., 2018]

2D: realistic



Quantitative agreement with MMS EDR observation of 2D laminar reconnection

2D Hybrid global



[Karimabadi et al., 2014]

- Prediction from computing power:
  - 2020-2030: 3D Hybrid global, 3D full kinetic local
  - 2030-2040: 3D kinetic global
- Connections to realistic ionosphere need to be included
- Model validation from observation important

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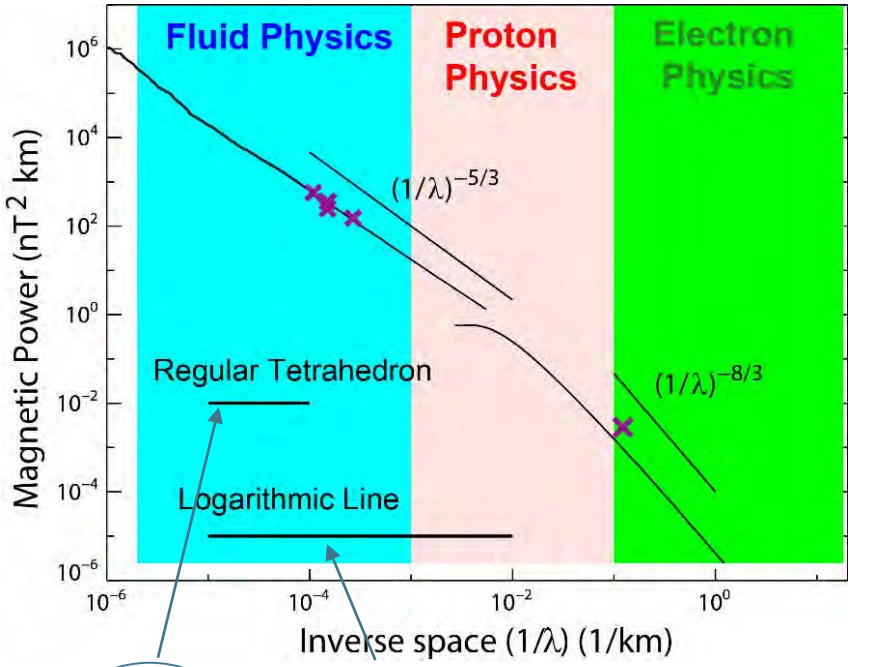
OBSERVATIONAL CHALLENGE FOR UNDERSTANDING GEOSPACE PLASMA PROCESSES

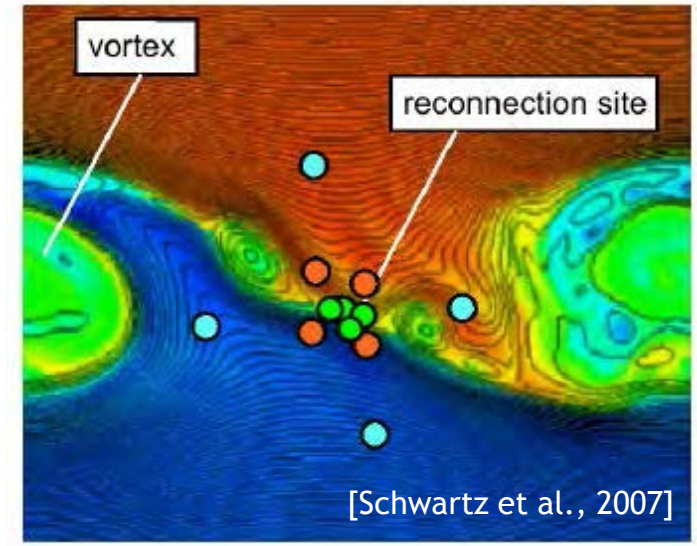
Multi-scale processes →



[Courtesy of O. Roberts]

limitation of 4 sc measuremets for turbulence spectra

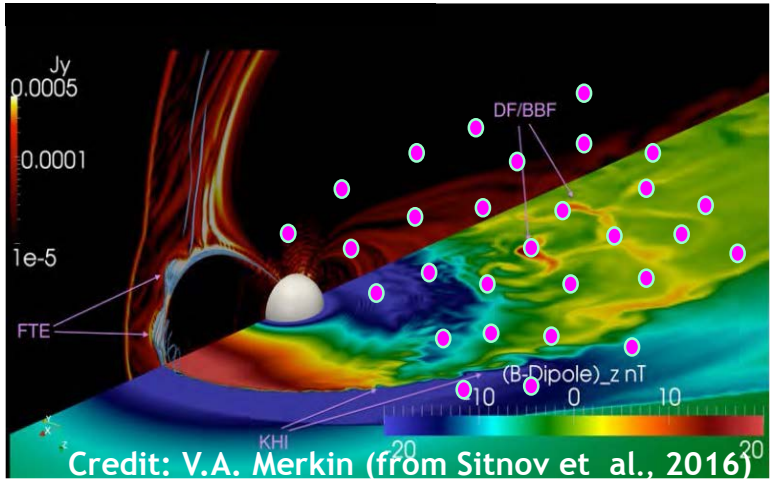
Combined macroscopic and microscopic observations essential



[Schwartz et al., 2007]

cross-scale coupling observation for vortex induced reconnection ?

Solar wind Magnetosphere Ionosphere Link Explorer (SMILE)



global sc constellation to understand global context ?

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SUMMARY

- MMS resolved electron diffusion region of a 2D laminar reconnection in magnetotail.(Exceptional case)
- Spatial scale and reconnection electric field support the idea that inner EDR has a dimension of meandering electrons in the field reversal region.
- Reconnection electric field and inner EDR width (Δ_N~1 de) similar to PIC simulation, but (inner) EDR length Δ_L~0.1 di shorter than PIC simulation
  → EDR dimension controlled by outside process, such as multiple reconnection → larger-scale simulation necessary ?
- Ion-scale properties suggests 3D (dawn-dusk gradient expected) as well as multiplicity (flux ropes, flapping, ground-based magnetic field variations)
  → Consequence/context of entire reconnection is more complex
- Important to have multi-scale measurement due to (1) 3D (2) transient (3) multiple nature of magnetotail reconnection with (4) large-scale consequences