

Identifying active magnetic reconnection in simulations and in situ observations of plasma turbulence using magnetic flux transport

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Reconnection has been suggested to play an important role in the evolution of plasma turbulence by observations, simulations and theory, including:

- **dissipating turbulence energy** (Dmitruk et al, ApJ, 2004, Sundkvist et al, PRL, 2007, Osman et al, ApJL, 2011, PRL, 2012, Markovskii & Vasquez, ApJ, 2011, Perri et al, PRL, 2012, Wan et al, PRL, 2012, Karimabadi, et al, POP, 2013, TenBarge & Howes, ApJL, 2013, Wu et al, ApJL, 2013, Zhdankin et al, ApJ, 2013, Shay et al POP, 2018)
- **altering the turbulent cascade** (Loureiro & Boldyrev, PRL, 2017a, ApJ, 2017b, Boldyrev & Loureiro, ApJ, 2017, Mallet et al, MNRAS, 2017a, JPP, 2017b, Franci et al, ApJL, 2017, Vech et al, ApJL, 2018, Stawarz et al, ApJL, 2019)

Methods to identify reconnection in turbulence

Observations and simulations:

- Alfvénic ion or super-Alfvénic electron outflow jets as a signature
- Outflow jets can be distorted by turbulence, especially at kinetic scales

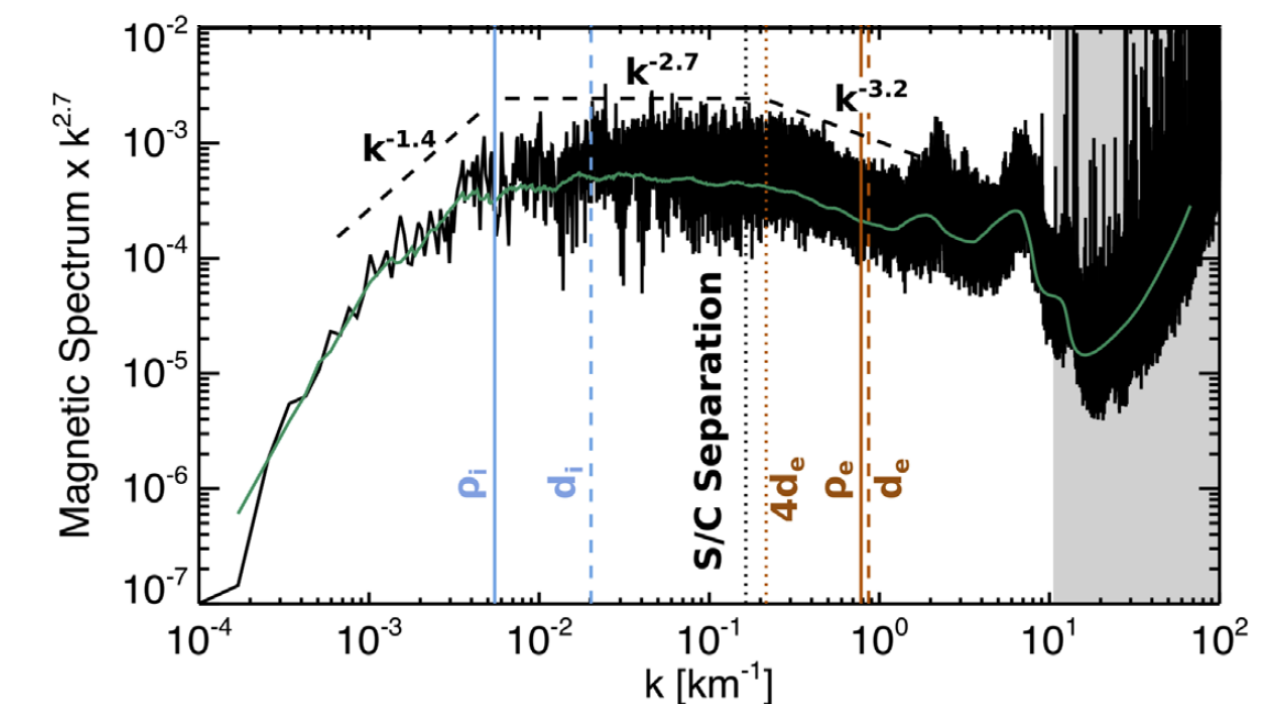
Simulations:

- Saddle point method (e.g., Servidio et al, PRL 2009, Wan et al, POP, 2013, Haggerty et al, POP, 2017)

Indicators

- Strong currents and/or fast flows (e.g., Zhdankin et al, ApJ, 2013, Agudelo et al, JPP 2021)
- Based on ExB velocity (Lapenta, ApJ, 2021, Pongkitiwanichakul et al, ApJ, 2021)

MMS observation: spectral steepening at electron scale (Stawarz et al 2019)



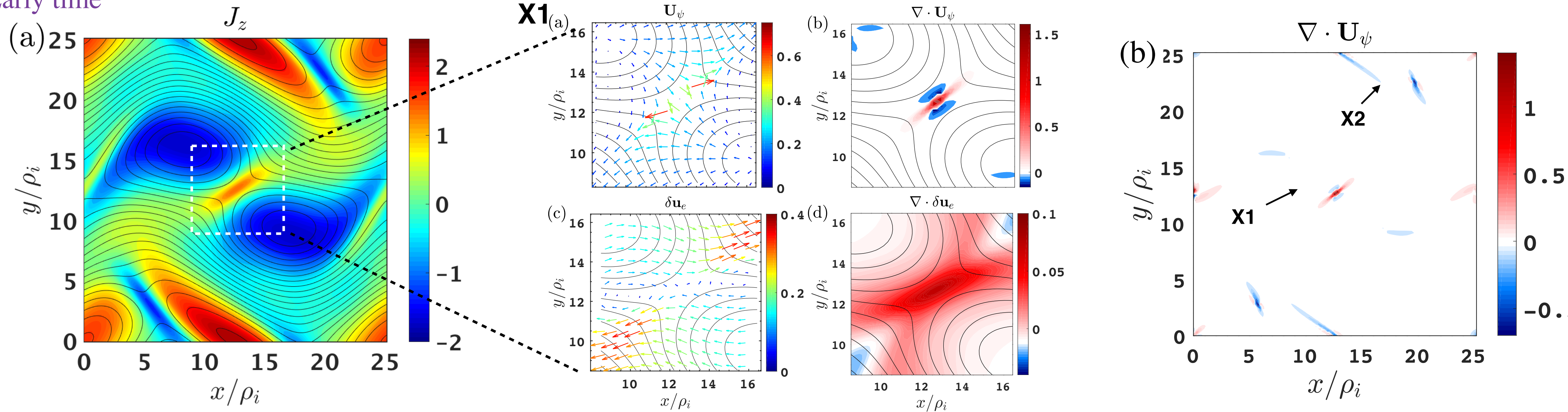
Our goal is to develop a reliable and accurate method:

- provides reconnection signature
- applicable to simulations and observations

Magnetic flux transport (MFT) identifies active reconnection in turbulence

Li et al, ApJL, 2021

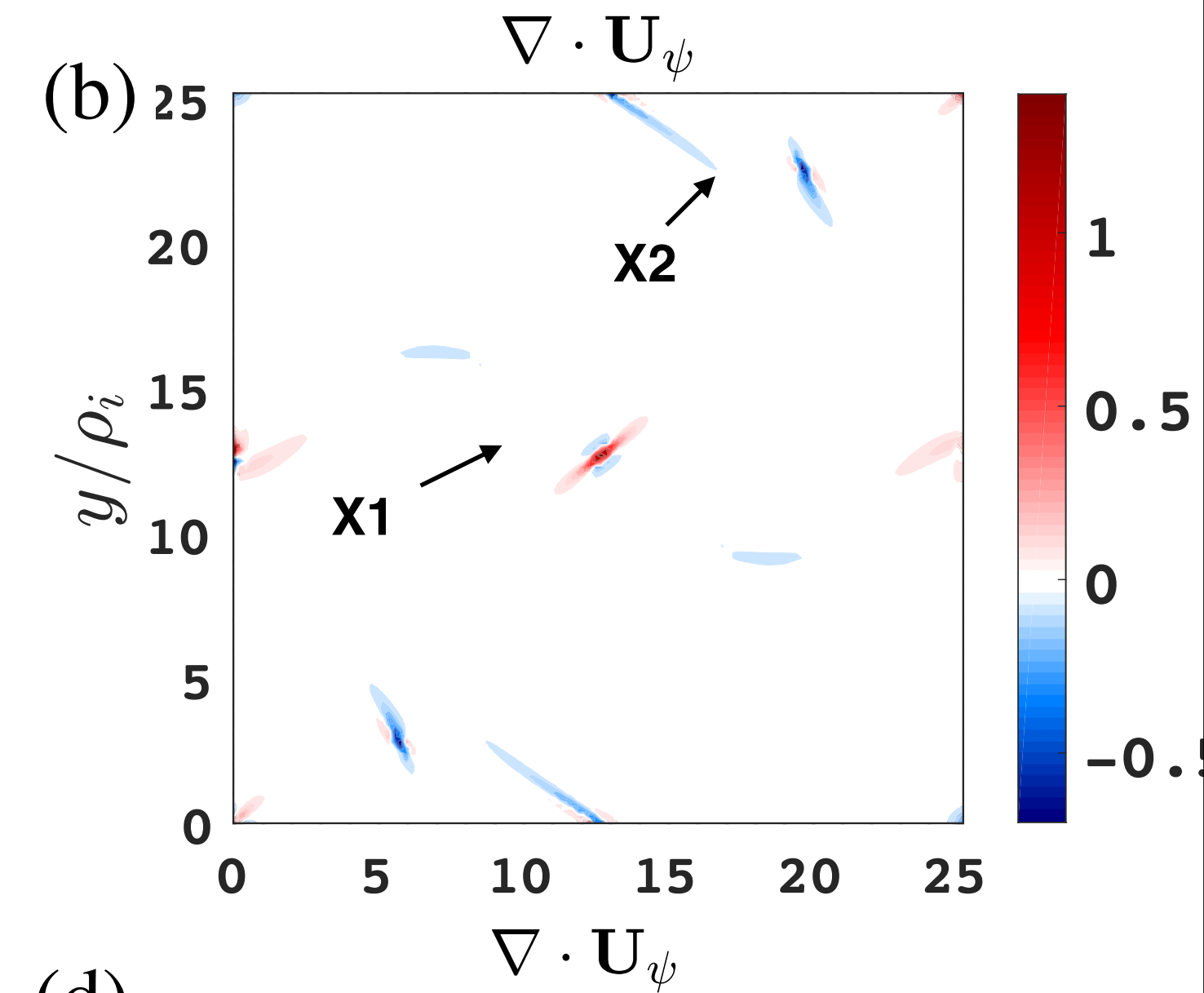
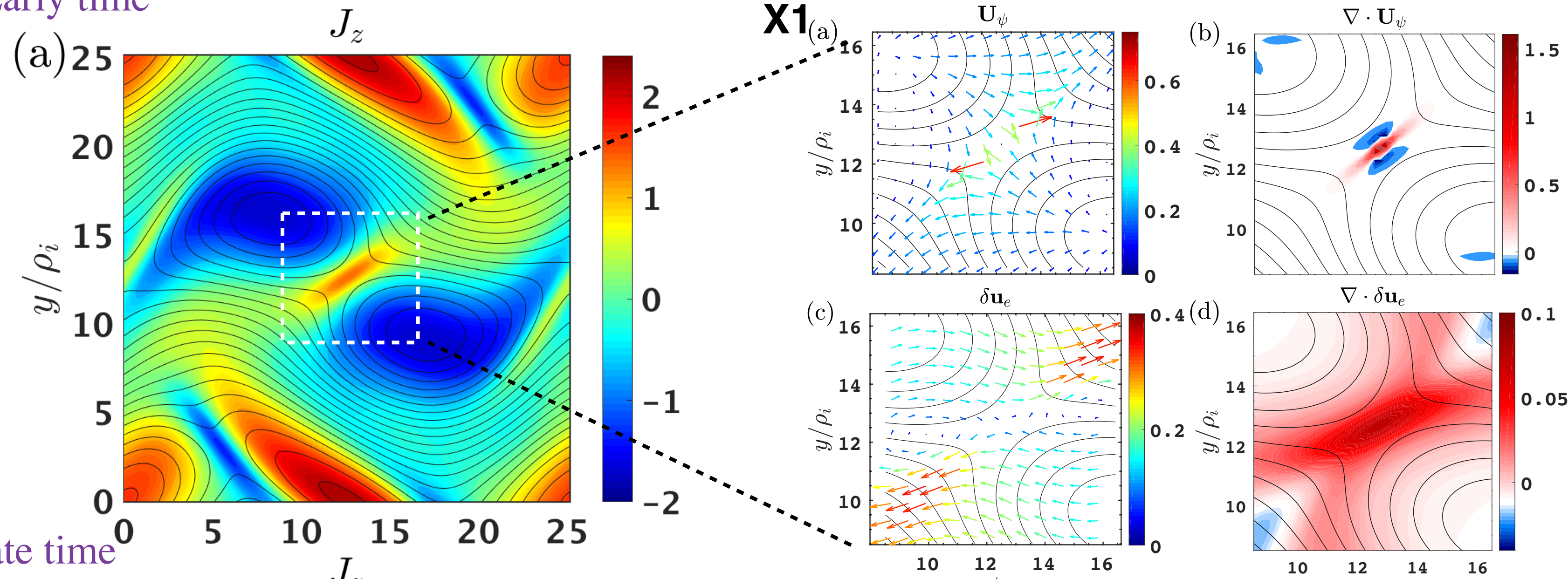
Early time



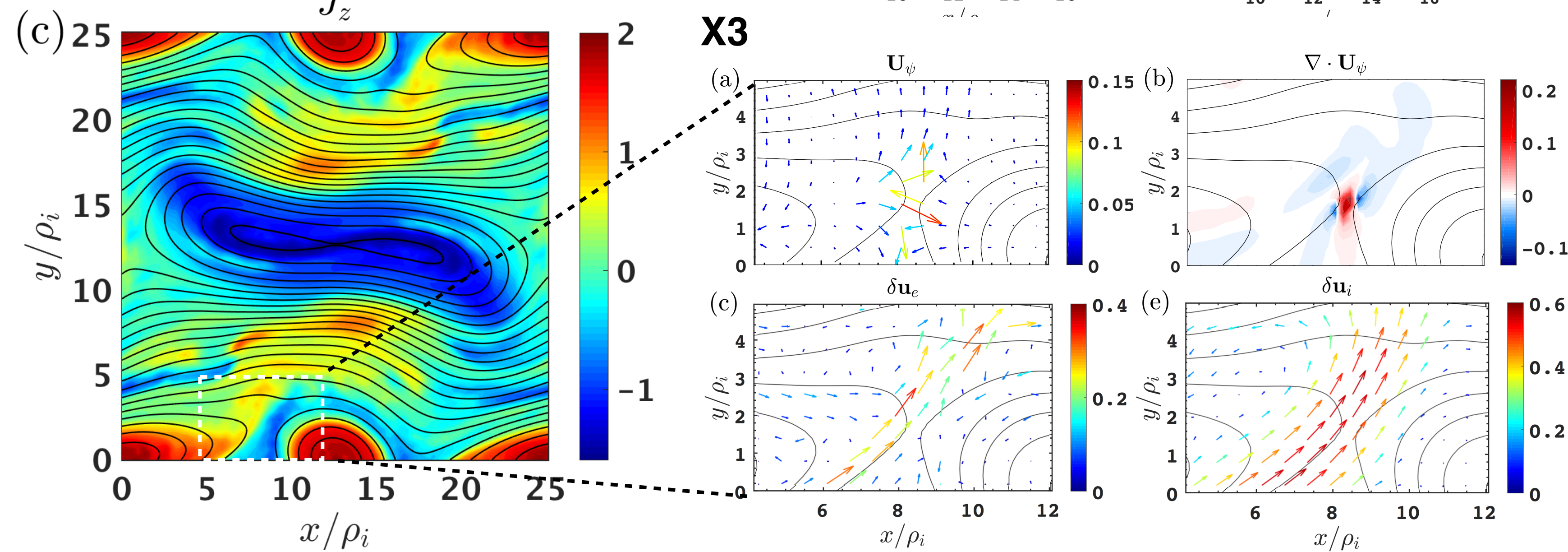
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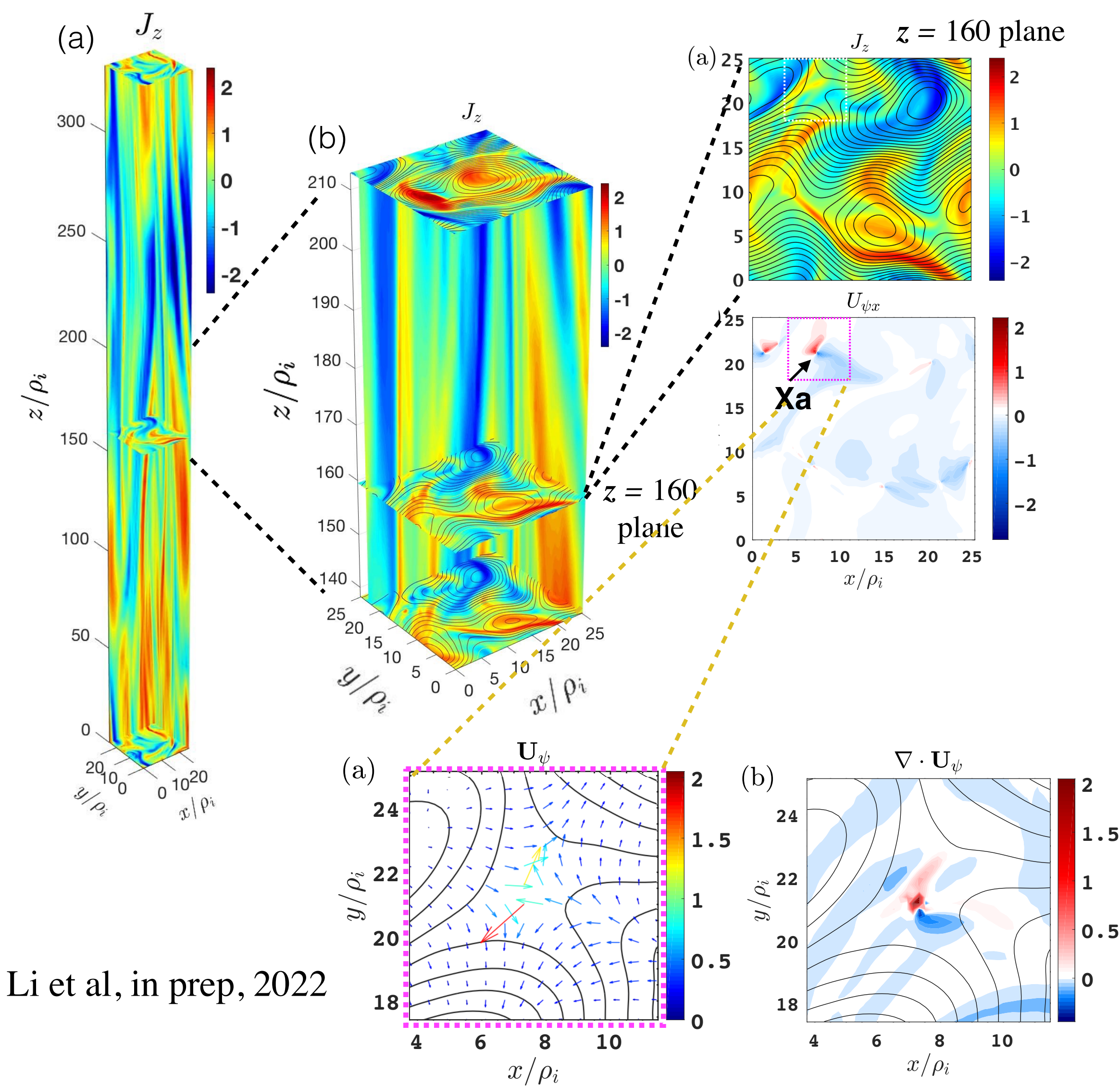


Late time



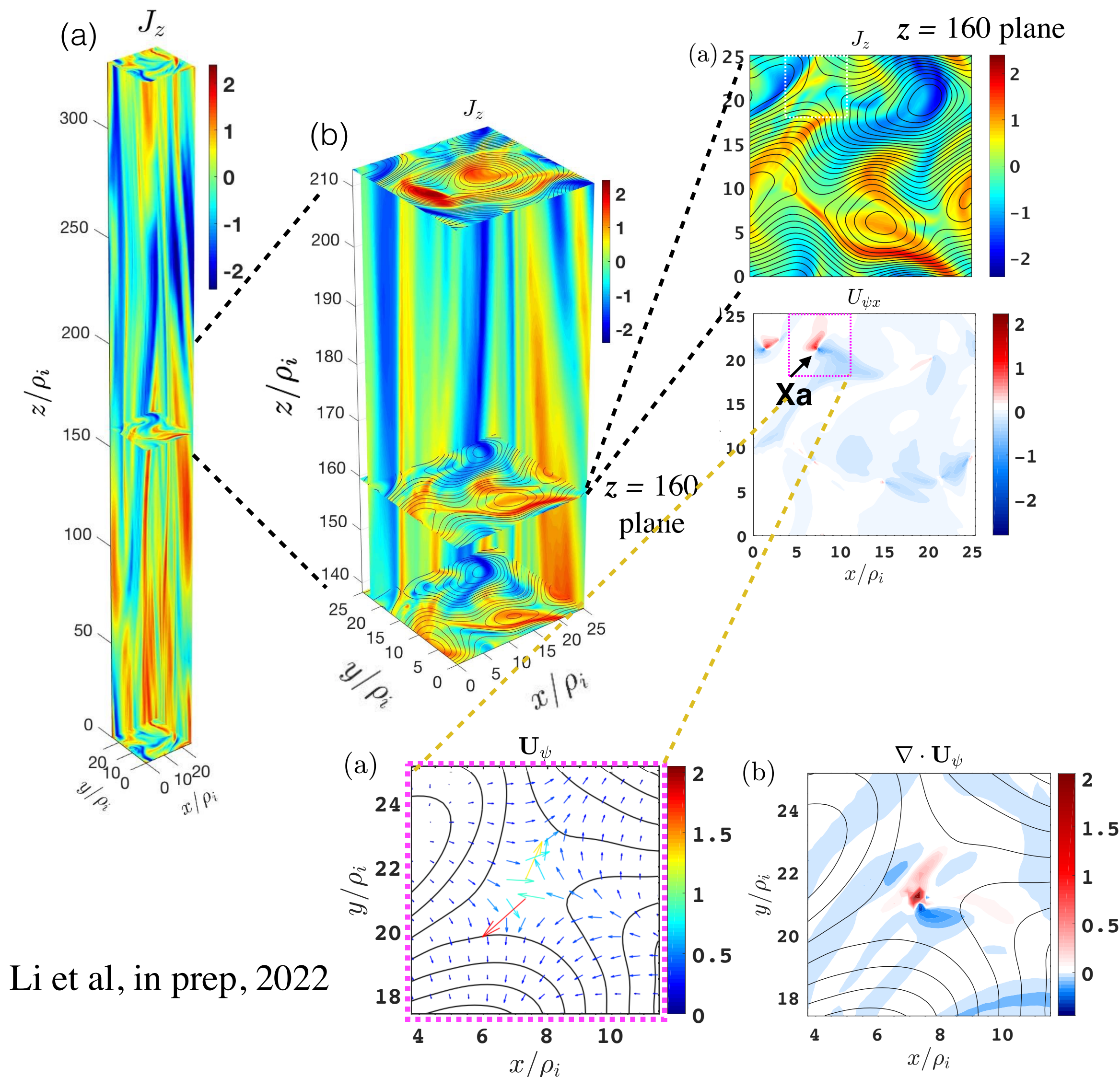
Magnetic flux transport in 3D kinetic turbulence

Plenty of active reconnection X-lines are identified using MFT.



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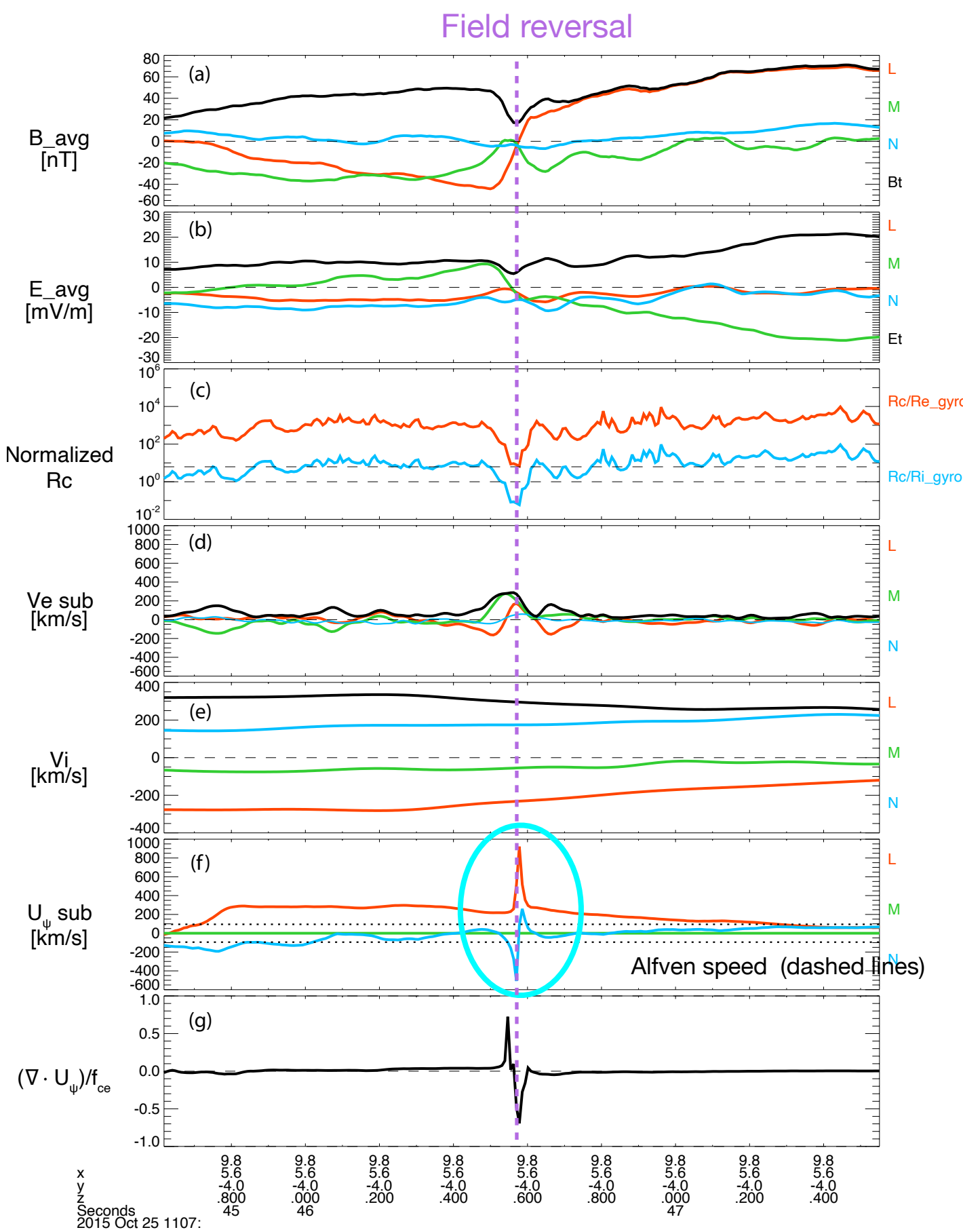


Li et al, in prep, 2022

Magnetic flux transport in MMS observations:

We analyzed 37 reconnection events throughout the magnetosphere.

All of them can be successfully identified through MFT signatures

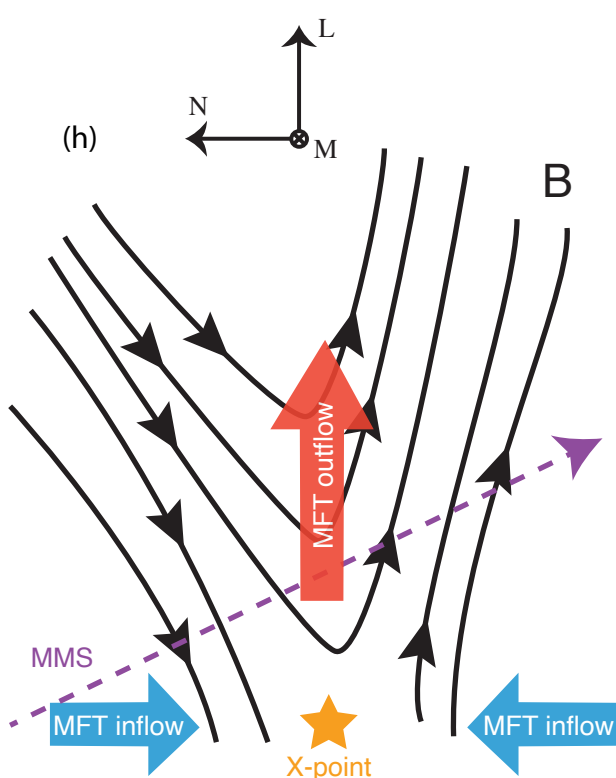


2015 Oct 25 event (Eriksson et al 2018) in the turbulent magnetosheath

(f) Bi-directional inflow MFT jets and super-Alfvenic outflow jet

Consistent with simulation

If interested, please see talk by Qi et al, ST1.12



Yi Qi et al, ApJL, 2022

Conclusion

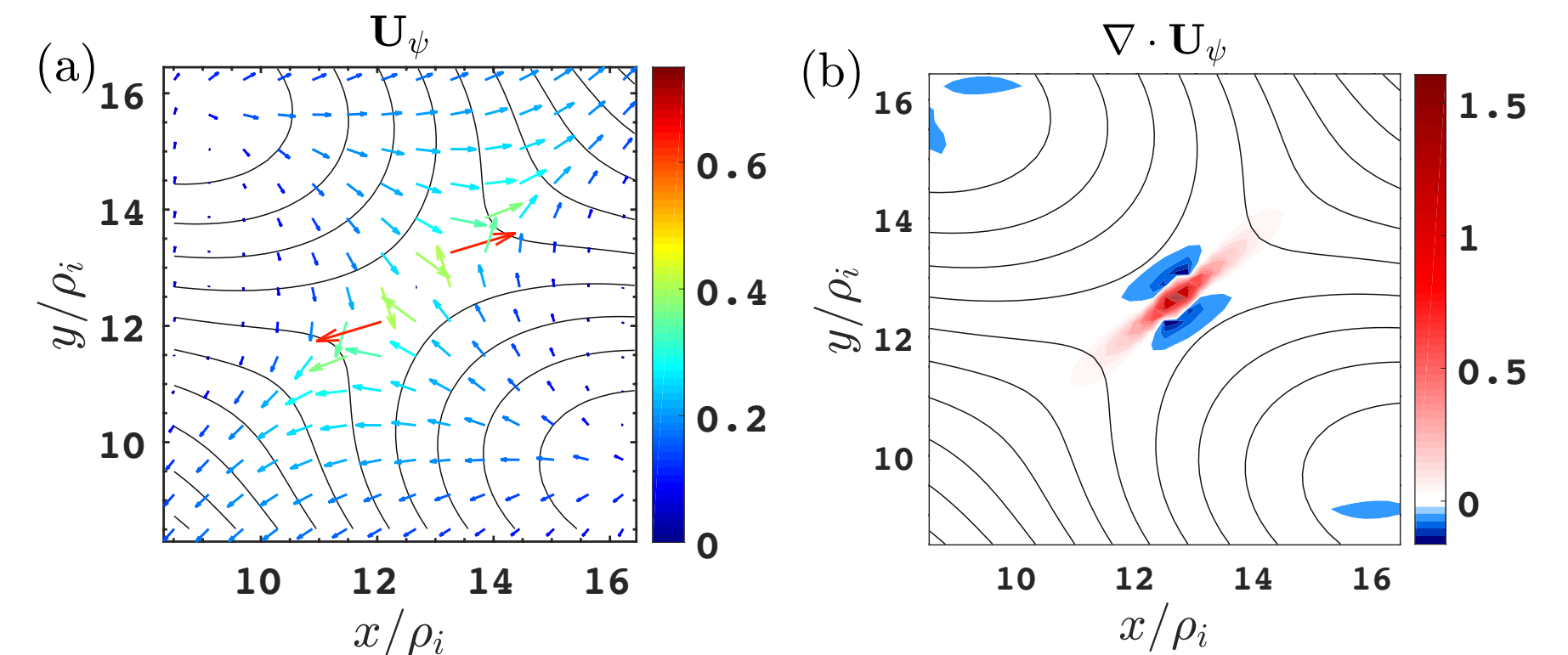
- A new method based on magnetic flux transport (MFT) has been recently developed for identifying active reconnection
- It provides clear signatures in $\mathbf{U}_\psi$ and $\nabla \cdot \mathbf{U}_\psi$ even in turbulence, where electron and ion outflows can be distorted or suppressed.
- Demonstrated in 2D and 3D simulations and MMS observations
- Applicable to simulations and in situ measurements from spacecraft missions, including PSP and Solar Orbiter.

References

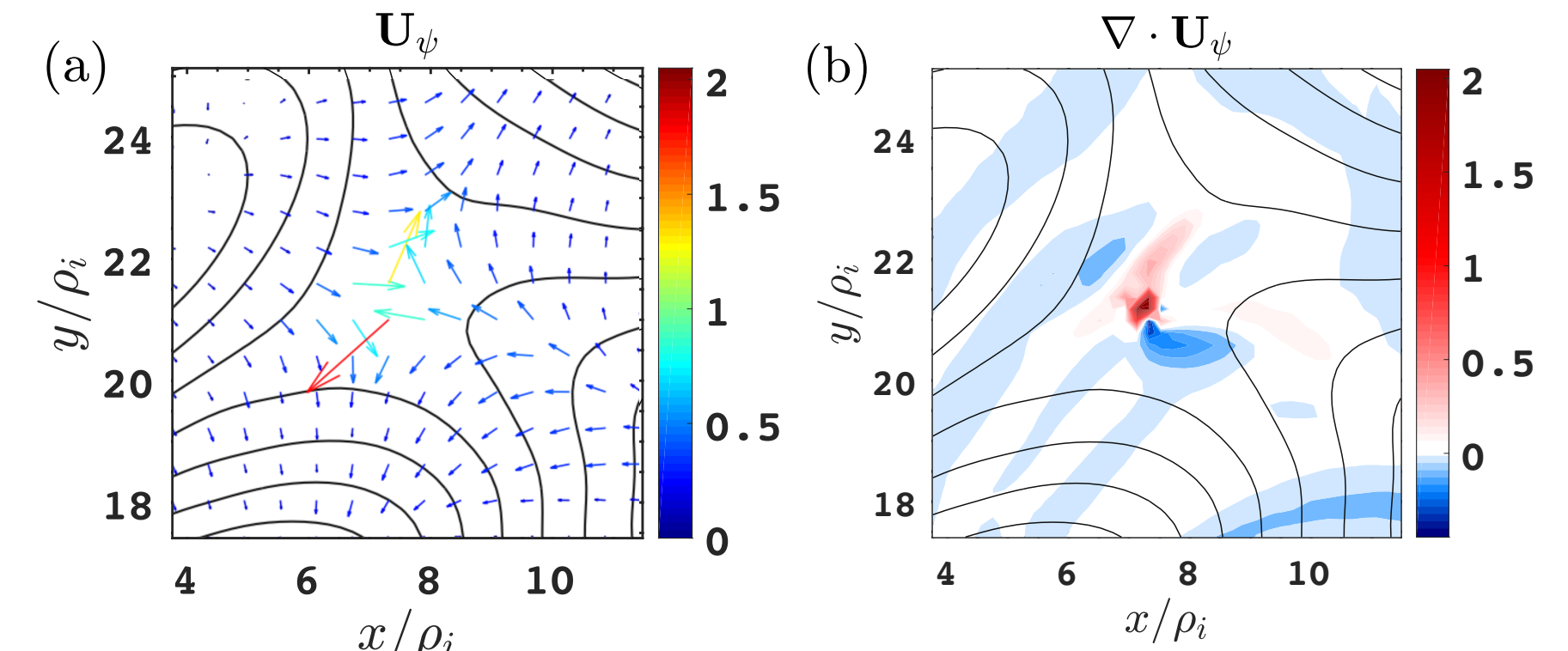
1. Tak Chu Li, Yi-Hsin Liu, and Yi Qi, "Identification of Active Magnetic Reconnection Using Magnetic Flux Transport in Plasma Turbulence," ApJL, 2021
2. Yi Qi et al, "Magnetic Flux Transport Identification of Active Reconnection: MMS Observation in the Earth's Magnetosphere," ApJL, 2022

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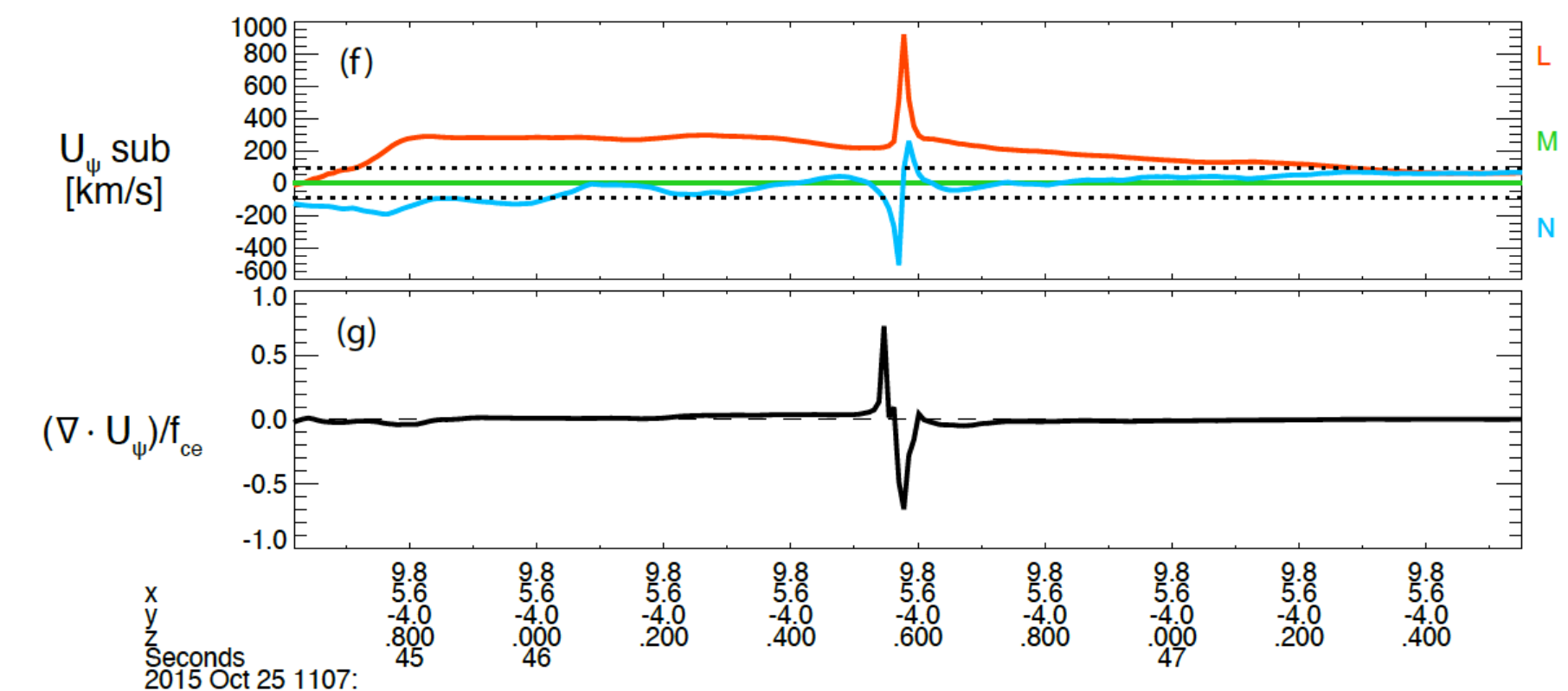
2D simulation



3D simulation



MMS observation



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Conditions for applying MFT

(1) Scale of variation along background B field $\gg$ perpendicular scale, i.e., $k_{\parallel} \ll k_{\perp}$

- Consistent with anisotropic turbulence theory and observations in the solar wind and magnetosheath (Cho & Lazarian, ApJL, 2004, Alexandrova et al, An. Geophys., 2008, PRL, 2009, Schekochihin et al, ApJ, 2009, Sahraoui et al, ApJ, 2013, Chen, JPP, 2016)

(2) Quasi-planar reconnection

- Consistent with the local current sheet coordinate, obtained even in small-scale current sheets in the turbulent magnetosheath (e.g. Phan et al, Natr, 2018, Wilder et al, JGR, 2018, Stawarz et al, POP, 2022)