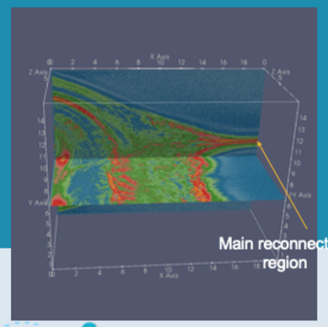
KU LEUVEN | University of Colorado Boulder

3D Simulation of electron scale turbulent currents in reconnection outflows

G. Lapenta (KULeuven, SSI Boulder)
R. Dupuis, F. Pucci, J. Amaya (KULeuven)
M. Goldman, D. Newman, S. Eriksson (CU Boulder)

Acknowledgments

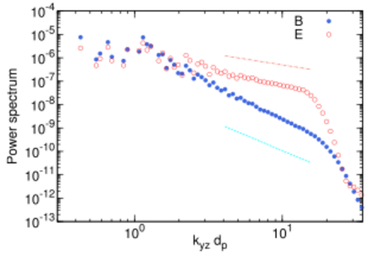
Turbulent reconnection outflow



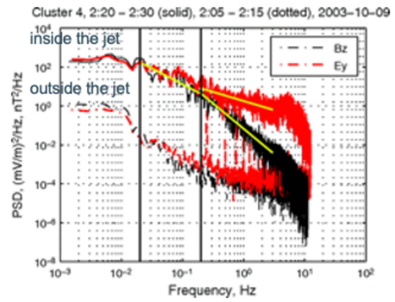
Key points

- Reconnection in 3D **PIC simulations with iPic3D** leads to a **turbulent outflow**
- The turbulence in the outflows has been observed in **Cluster and MMS data**
- Turbulence and reconnection cause **energzation of the particles**
- But what type of energization? **Is it heating or acceleration**?
- **Complexity** of the velcity distribution functions (VDF)
- Analysis of VDF with **gaussian mixture models (GMM)**
- The tool from **project AIDA** is used to do the analysis (**aida-space.eu**)
- The **"thermal energy"** of the second fluid moment is in reality the sum of the thermal energy of the beams plus a **"pseudo" thermal energy** that is in reality the **kinetic bulk energy of the relative motion between the gaussian beams**.

Turbulence in the outflow



Pucci et al, ApJ, **841**:60 (2017)

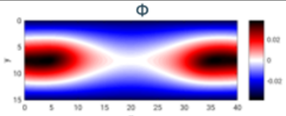


J. P. Eastwood, et al. , PRL **102**, 035001 (2009)

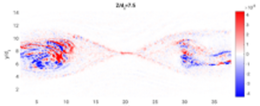
Mean and Standard Deviation of the energy terms

$J_e \cdot E$

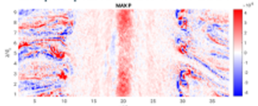
$$\frac{1}{2}\frac{\partial}{\partial t}\left(\epsilon_0 E^2 + \frac{1}{\mu_0}B^2\right) = -\sum_s \boxed{\mathbf{E}\cdot\mathbf{J}_s} - \nabla\cdot\mathbf{S}$$

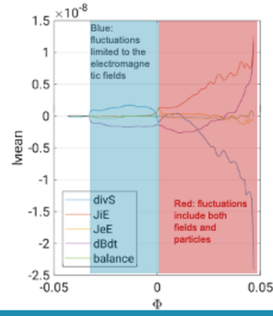


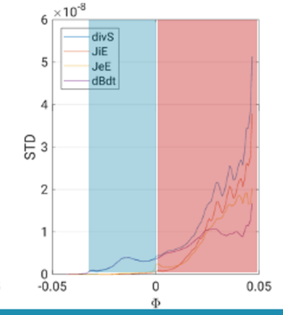
Meridian plane: Front view



Ecliptic plane: View from above

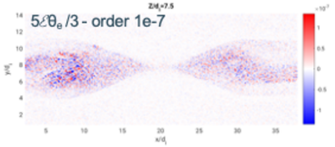




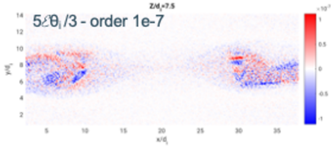


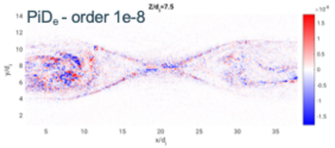
Energy dissipation via the pressure tensor

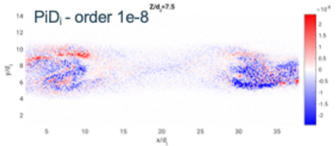
electrons



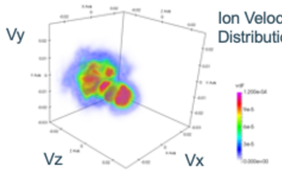
ions

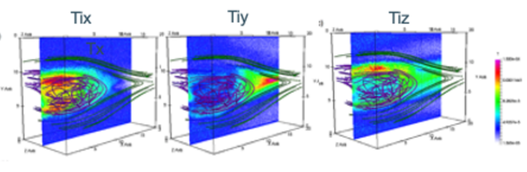


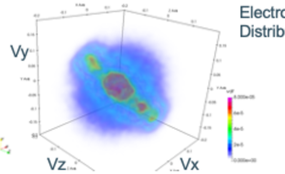


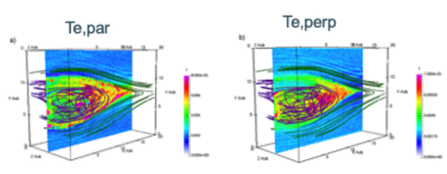


Energization: Velocity distributions

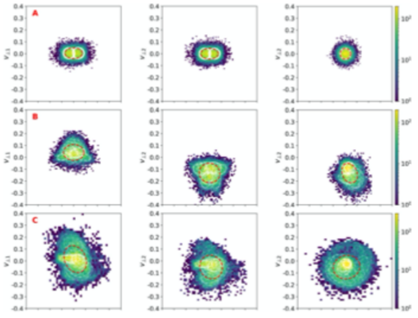








Gaussian Mixture Model (GMM): Different distributions

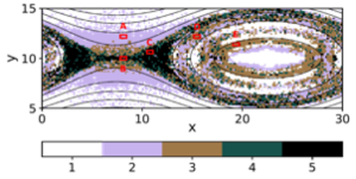


$$p(\boldsymbol{x}|\boldsymbol{\Phi}) = \sum_{k=1}^{K} w_k \mathcal{N}(\boldsymbol{x}|\boldsymbol{\theta}_k)$$

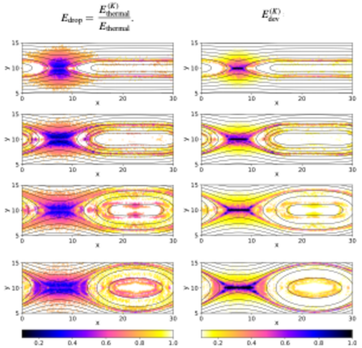
Determination of the number of Gaussians:

- Akaike information criterion (AIC): $2k - 2\ln(L)$
- Bayesian information criterion (BIC): $\ln(n)k - 2\ln(L)$,

k = number of Gaussians; L = likelihood



Effect on the definition of thermal energy



- Fluid thermal energy:

$$E_{thermal} = \frac{1}{N_p}\sum_{i=1}^{3}\left[\sum_p (\boldsymbol{V}_p - \langle \boldsymbol{V}_p\rangle)^2\right], \text{ with } \langle \boldsymbol{V}_p\rangle = \sum_p \frac{\boldsymbol{V}_p}{N_p}.$$

- Multibeam thermal energy

$$E^{(K)}_{thermal} = \frac{1}{2}\sum_{i=1}^{3}\sum_{k=1}^{K} w_k^2[\boldsymbol{\sigma}^2_k]_i.$$

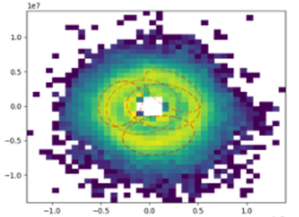
- Drop in thermal energy

$$E_{drop} = \frac{E^{(K)}_{thermal}}{E_{thermal}}.$$

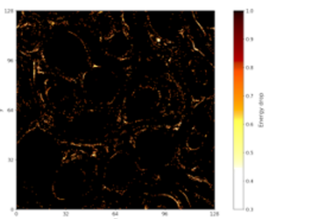
- Pseudo ("false") thermal energy

$$E^{(K)}_{dev} = \sum_{i=1}^{3}\left[\sum_{k=1}^{K} w_k(\mu_k)^2 - \left(\sum_{k=1}^{K} w_k(\mu_k)\right)^2\right].$$

Extension to MMS observations and turbulence simulations



Reconnection event: 16 October 2015-13:07:02.235



Regions of interest from turbulent simulations

Currently working on more modern methods, such as 3D Auto Encoder to deal with a lot of different particle distributions.