Automated characterization of magnetic reconnection using particle distributions

Romain Dupuis¹, Jorge Amaya¹, Giovanni Lapenta¹, Martin Goldman², and David Newman²

¹Katholieke Universiteit Leuven, KU Leuven, Centre for mathematical Plasma-Astrophysics, Belgium
²University of Colorado, Boulder, CO 80309, USA

Magnetic reconnection is a fundamental process for many plasma phenomena converting the stored magnetic energy into kinetic energy, thermal energy, and particle acceleration energy. Various missions have been launched, the latest being Magnetospheric Multiscale Mission (MMS), to improve the understanding of reconnection with in-situ measurements. In particular, particle distributions provide a rich insight on the local physics but a unique specific distribution cannot be used as a signature for reconnection as it does not reflect the phenomenon for all the possible external conditions. For instance, a strong anisotropy can be observed near the electron exhaust [1] while crescent-shaped distributions can be detected near the electron stagnation point for asymmetric reconnection [2].

From Particle-In-Cells (PIC) simulations, we developed a detection algorithm using a machine learning technique called Gaussian Mixture Model approximating the underlying density function by a sum of Gaussians [3]. The objective is twofold: finding a good approximation for the distribution while keeping a statistical meaning to the different components of the sum. The deviation from classical Maxwellians and the distributions with complex shapes provide a good measurement to identify reconnection. The algorithm was successfully applied to 2.5D simulations and large regions around the diffusion region and the separatrix were spotted. Different kinds of distributions have been efficiently identified.

The presented results tend to extend this method to other sources of data:

- **3D simulations**: although reconnection in 2D is well understood, many unanswered questions persist for 3D systems. Usually, such simulations show regions of millions of kilometers while having a sufficient resolution to be able to observe the tiny regions in which the original reconnection events occur. A deep analysis and understanding of these very large simulations appear as very challenging. Therefore, we expect that our method supports the analysis by automatically identifying various regions of interest with potential reconnection.

- **Observational data**: as the model has been validated on simulations, we are interested to apply the method on real data from the MMS mission. Will the observations made by scientists of the mission compare with the result of a fully automatic tool? In particular, the data pre-processing providing cleaned and readable data to the algorithm is very challenging.
In conclusion, the Gaussian Mixture Model approach is a first attempt to automatically characterize various kinetic behaviors encountered in both numerical simulations and space missions. In particular, it represents a very good potential to support data analysis of spacecraft observations but also fully three-dimensional simulations.

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