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Determining the multi-spacecraft path across plasma structures from magnetic field data

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In this work we present new ways to determine the spacecraft path across the Earth's magnetopause applicable to multi-spacecraft missions such as the ESA CLUSTER mission and the NASA Magnetospheric MultiScale (MMS) mission.

The observational studies in space plasma physics deal with time series of data measured by spacecraft that cross unknown plasma structures. The geometrical features (e.g. orientations and dimensions) of these structures are key features to understand the physical phenomena at play (e.g. magnetic reconnection), but the time-to-space conversion procedure of data cannot be done without strong assumptions about the structures themselves. As a consequence, the results obtained in this way depend on the validity of these hypotheses. Furthermore the aid of numerical simulations can be misleading both due to the difficulty in interpreting satellite data to correctly initialize the simulations and because the evolution of the real plasma can differ from its virtual counterpart due to the simplifying assumptions on the boundary conditions and the governing equations used.

Up to now, concerning in particular the magnetopause location, the normal direction and its thickness, most of these determinations have been performed considering the magnetopause boundary as a structure strictly stationary and 1D (or with a simple curvature). This has been done using different parameters (magnetic field or plasma properties) often leading to different results. Furthermore, these determinations have shown to be very sensitive to the accuracy of the normal direction because it implies the projection of vectors (magnetic field and velocity) mainly perpendicular to this direction. Besides, the 1D stationary assumption is rarely verified at the real magnetopause.

The high quality measurements of MMS and their high time resolution now allow investigating the magnetopause structure in its finest features and with an unequaled spatio-temporal accuracy. We make use here of the MDD and RTD tools developed by Shi et al. [2005, 2006], together with new methods implemented by us. It allows computing the dimensionality and the normal direction locally, without assuming that this direction is constant all along the crossing. In this way we can calculate the spacecraft path across the magnetopause, which has never been estimated up to now otherwise than by hand sketches. We can so deduce the thickness of this boundary and the properties of the sub-structures without the usual full 1D assumption, only keeping the assumption that the structure is approximately stationary during the crossing.

By applying these methods to various quantities, we can ultimately draw their profiles as functions of a physical abscissa (length instead of time) along a reliable normal. This procedure allows answering quantitatively the questions concerning the locations and the thicknesses of the different sub-structures encountered inside the "global magnetopause" [Rezeau, 2017].

References

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