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Electromotive field - The missing puzzle piece of space plasma turbulence

Yasuhito Narita[1,2] and Philippe-A. Bourdin[3]
[1] Institute of Theoretical Physics, Technical University of Braunschweig, Braunschweig, Germany,
[2] Max Planck Institute for Solar System Research, Göttingen, Germany,
[3] Institute of Physics, University of Graz, Graz, Austria
e-mail (speaker): y.narita@tu-braunschweig.de

The concept of electromotive field (also referred to as the the electromotive force or simply as the EMF) plays a crucial role in various space and astrophysical fluids such as the dynamo mechanism generating the large-scale magnetic fields and the turbulent mixing phenomenon. The earlier studies of the EMF were limited to theoretical and numerical methods. In recent years, however, the observational approaches are just being developed by making extensive use of single and multiple spacecraft in space plasmas [1-3].

EMF represents one of the second-order moments of the fluctuating field such as the magnetic field and the flow velocity, and completes the covariance tensors of magnetohydrodynamic turbulence. The other second-order moments are the fluctuation energies (magnetic and kinetic energy) and the helicities (magnetic helicity, current helicity, kinetic helicity, and cross helicity). The EMF is unique in that the field is observationally accessible through the off-diagonal elements of the cross-covariance tensor multiplying the magnetic field and the flow velocity, while the cross helicity is accessible through the diagonal elements of the cross-covariance tensor.

The total fluctuation energy, the magnetic helicity, and the cross helicity are known as the invariants of ideal magnetohydrodynamics. We address the question, "Is the EMF an independent variable, or depending variable in describing the statistical behavior of plasma turbulence?" The motivation for this question comes from the empirical fact that the EMF has successfully been modeled as a function of the large-scale field (magnetic field and flow velocity) and the small-scale turbulence properties (fluctuation energy and helicities), and the model provides a reasonable explanation to various dynamo realizations such as the solar and the planetary magnetic field generation.

Naively speaking, one may speculate that the concept of the EMF should be applicable to turbulent phenomena in space plasmas, which implies that the dynamo mechanism may be operating under favorable conditions and that turbulent space plasma domains potentially serve as the natural laboratory of dynamo mechanism through the studies of EMF using in-situ magnetic field and flow velocity measurements.

We test for the EMF concept against two distinct space plasma phenomena: (1) interplanetary coronal mass ejections, and (2) dipolarization front of the Earth magnetotail. The spacecraft data analysis for the solar wind using the Helios mission and for the Earth magnetotail using the MMS mission show that the EMF is enhanced together with the magnetic field amplification. Moreover, the EMF model in the mean-field electrodynamics can reasonably reconstruct the direct measurement of the EMF.

Our experience suggests not only that the dynamo theory can be quantitatively tested against space plasma observations, but also that the EMF itself serves as a useful diagnostic tool to characterize the shocks and other spatial structures in turbulent plasmas.

References

[1] Bourdin, Ph.-A., and Narita, Y., Rev. Mod. Plasma Phys., 9, 1, 2025.
[2] Narita, Y., Ann. Geophys., 39, 759, 2021.
[3] Bourdin, Ph.-A., Hofer, B., and Narita, Y., Astrophys. J., 855, 111, 2018.