A Novel Method for Magnetohydrodynamic Simulations and Its First Applications in Astrophysics and Cosmology on High Performance Computational Systems

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ABSTRACT

Magnetic fields are one of the most important phenomena in science and engineering, as they are present on almost every scale in nature, ranging from atomic magnetic moments to the intergalactic scales, and are used in applications ranging from Magnetic Resonance Imaging to nuclear fusion.

In this work we first present a novel powerful method for high performance magnetohydrodynamic (MHD) calculations which is based on kinetic schemes. In particular, using it, it is possible to derive the MHD equations directly from the Boltzmann Equation without the necessity of an *ad hoc* introduction of terms related to electromagnetic interactions.

With that at hand, we were then able to apply the method to one of the most important problems in present day astrophysics and cosmology, namely to the question of the origin and time evolution of Intergalactic Magnetic Fields. As for their origin, there are mainly two scenarios discussed in the literature – on the one hand the cosmological one, where the magnetic field is produced by some process in the very early Universe, and on the other hand the cosmological one, where a seed of the magnetic field is created during structure formation and then amplified by some dynamo effect.

Here, we show first results of the aforementioned application of our method – on the one hand, concerning the astrophysical scenario, the simulation of galactic winds, i.e. the ejection of matter from galaxies which might also carry magnetic energy, and on the other hand, for the cosmological scenario, the time evolution of primordial magnetic fields and their possible imprints on the Cosmic Microwave Background (CMB).

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REFERENCES

[1] Chetverushkin, B.N. and D'Ascenzo, N. and Saveliev, A.V. and Saveliev, V.I. *Novel Kinetically Consistent Algorithm for Magneto Gas Dynamics.* Appl. Math. Lett. (2017) **72**, pp. 75–81.