Magnetic fields: Relics from the Early Universe

Primordial Magnetic Fields through Large Scale Structure

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In Short

- Large scale magnetic fields are ubiquitous in our Universe. Recent observational evidences strengthen the idea that they should have a primordial origin.
- We study how different primordial magnetogenesis scenarios make an impact during the large-scale formation.
- We use the massively parallel numerical, magneto-hydrodynamical cosmological ENZO code with adaptive mesh refinement in order to study the most massive elements of the cosmic web.

Different observational techniques developed over the last decades in the search of extragalactic magnetic fields have revealed the existence of correlated magnetic fields on various scales of the Universe. Faraday rotation measurements of extragalactic sources (as well as synchrotron emission, CMB polarization data, etc.) have shown that the strength of these magnetic fields is of the order of microGauss on galaxies and galaxy cluster scales. The origin of these magnetic fields is still under debate, nevertheless it is plausible that they have been generated in the Early Universe. The constraints from big bang nucleosynthesis (BBN) itself set an upper limit on the strength of these fields of 10^{-6} Gauss by requiring that at the time of Nucleosynthesis average energy density in magnetic fields should be significantly less than the radiation energy density, while this limit is also obtained by the cosmic microwave background anisotropies. Recent observations of blazar spectra suggest $10^{-18} - 10^{-19}$ Gauss as a lower bound for these fields, in favor of the existence of a primordial magnetic field seed.

The generation mechanisms of primordial magnetic fields are divided into two broad classes: (i) inflationary and (ii) phase transition magnetogenesis. Each of these mechanisms lead to different properties, such as strength, spectral signatures, and correlation lengths that can be corroborated with observations. In this project, we study for the first time how magnetic field seeds generated via i) and ii) mechanisms will evolve during large-scale formation (LSS). We aim to study the different features imprinted in the most massive elements in the cosmic web, namely galaxy clusters and filaments, in order to distinguish in between these primordial scenarios.

Several magneto-hydrodynamical (MHD) simulations of early Universe have proved that different magnetogenesis scenarios lead to different and unique configurations of the resulted magnetic energy spectrum [1,2]. In [2], we studied the evolution of magnetic fields generated during the expansion of the universe from the electroweak epoch until the epoch of recombination. In Fig.1, we show the main results of these studies where we estimate if they can serve as the initial seed for the observed magnetic fields in galaxies and clusters. Specifically, the helical magnetic fields potentially reach nG strengths at scales up to 30 kpc today.

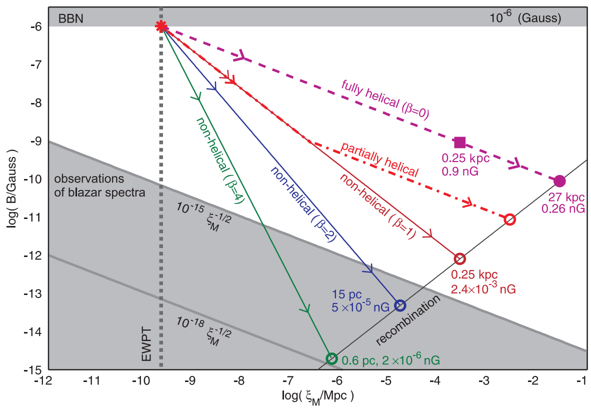

Figure 1: *Turbulent evolution of the magnetic field rms in [2]. The circles indicate the final points at recombination for zero or partial initial magnetic helicity, the filled circle marks the fully helical case, and the filled square indicates the case with the initial kinetic helicity. The regimes excluded by observations of blazar spectra and Big Bang Nucleosynthesis limits are marked in gray.*

On the other hand, there are few works on how a primordial magnetic seed can be amplified up to observable values with cosmological MHD grid simulations. In [5], the ENZO code (enzo-project.org) was used for the production of one of the largest grid cosmological simulations ever produced with an initial magnetic configuration which led to a sample of highly resolved galaxy clusters (highest resolution of 3.95 kpc). These simulations required aggresive AMR in order to sample turbulence in a volume filling way, reduce numerical dissipation effects and reach a higher Reynolds number. One of the main outcomes is that all of the simulated clusters were initialized to have an initial magnetic seed of 0.1 nG at $z = 30$ and finally reached values of $\sim$ 1-5 μG at $z = 0$ [4]. On the upper part of Fig.2 we show the projected magnetic field of one highly resolved galaxy cluster produced by a cosmological simulation with the ENZO code. On the lower part of Fig.2 we also show the magnetic energy spectra for various clusters in the produced sample.

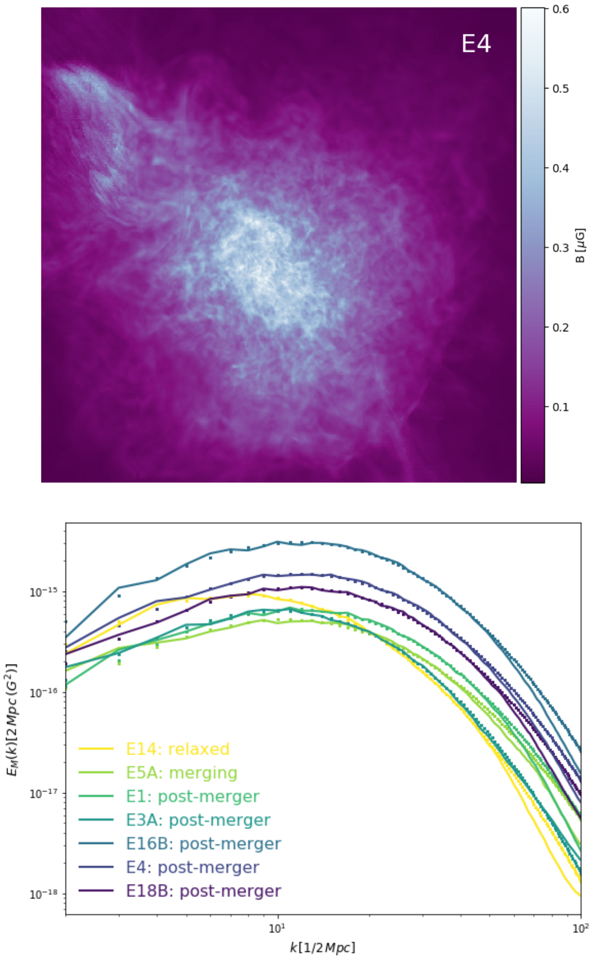

Figure 2: *Up: Projection of the magnetic field strength in a galaxy cluster of the sample at the highest resolution in [3,4]. Down: Magnetic energy spectra of all of the sample at z = 0. The solid lines correspond to the data and the scatter plots show our best-fit.*

In the proposed project we will extend these previous studies. Concretely, we will use the same setup for the MHD cosmological code ENZO as is used in [4], which will evolve primordial magnetic field seeds resulted from plausible magnetogenesis scenarios [1]. We will run our simulations in a comoving volume of 80 Mpc^3 and 256^3 root grid making use of the adaptive mesh refinement (AMR) feature of ENZO. Regions of interest, such as filaments and clusters will be re-simulated with higher resolution using a combination of static nested grids and AMR inside the nested-grid regions. This will allow us to follow the evolution of the magnetic fields from the early universe till late times of the large scale structure (LSS) formation and to produce a statistically significant sample of cosmic objects that can be used for comparison with current observations.

Our previous and present studies have shown that ENZO is a robust code for the studying the effects of magnetic fields on large-scale formation. The combination of our two recent studies (i.e [2,4]) gives us the unique opportunity to link this new project with a clear observational signature of extragalactic magnetic fields. The outcome of the desired cosmological simulations with different realistic magnetic field initial conditions will allow us to give a step further in the quest of understanding the origin of magnetic fields in our Universe.

WWW

https://cosmosimfrazza.myfreesites.net/amr_clusters

More Information

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