Spectral analysis of the magnetic field evolution in the ICM

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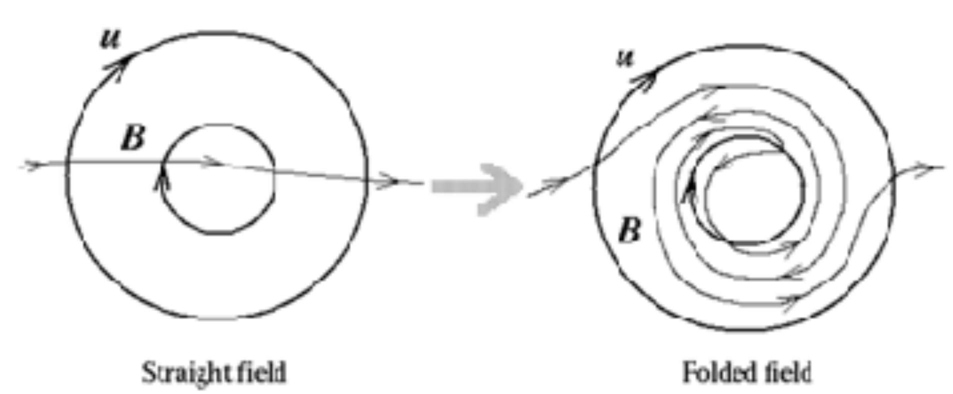
Abstract

- Despite of the magnetic fields origin in galaxy clusters, it is most likely that the seed fields are *amplified via a dynamo process*.
- In this work, we use results from dynamo theory in order to test the simulated formation of galaxy clusters.
- We use a customised version of the cosmological grid code *ENZO* with maximum resolution of 3.95 kpc/cell
- We show that the spectral magnetic energy shape for various clusters can be well fitted by one equation derived directly from dynamo theory.
- In the case of a highly perturbed cluster, our simulations show that this spectral analysis of the magnetic energy can give us information on the dynamics and merger history of the system.

Introduction

- **What is a small-scale dynamo?**

It is the process of conversion of kinetic turbulent energy into magnetic energy. It produces magnetic fields that are correlated on scales of the order of the energy scale of turbulence. Magnetic field lines are stretched, bent and folded by the random turbulent motions, resulting in an *amplification of the field*.



Scheckochihin et al. (2008)

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- **Kazantzev dynamo in Fourier space.**

The equation for the evolution of the magnetic power spectrum $M(k,t)$ in the kinematic limit is:

$$\frac{\partial M}{\partial t} = \frac{\gamma}{5}\left(k^2\frac{\partial^2 M}{\partial k^2} - 2k\frac{\partial M}{\partial k} + 6M\right) - 2k^2\frac{\eta}{4\pi}M$$

In the case where the magnetic diffusivity is negligible, i.e. $\eta = 0$, an analytical solution for this equation can be obtained:

$$M(k,t) = M_1\, e^{(3/4)\gamma\tau}\left(\frac{k}{k_{\rm ref}}\right)^{3/2}\left[1 - \mathrm{erf}\left[\sqrt{\frac{5}{4\gamma t}}\ln\left(\frac{k}{k_{\rm ref}}\right)\right]\right]$$

$$E_M(k) = A\,k^{3/2}\left[1 - \mathrm{erf}\left[B\ln\left(\frac{k}{C}\right)\right]\right]$$

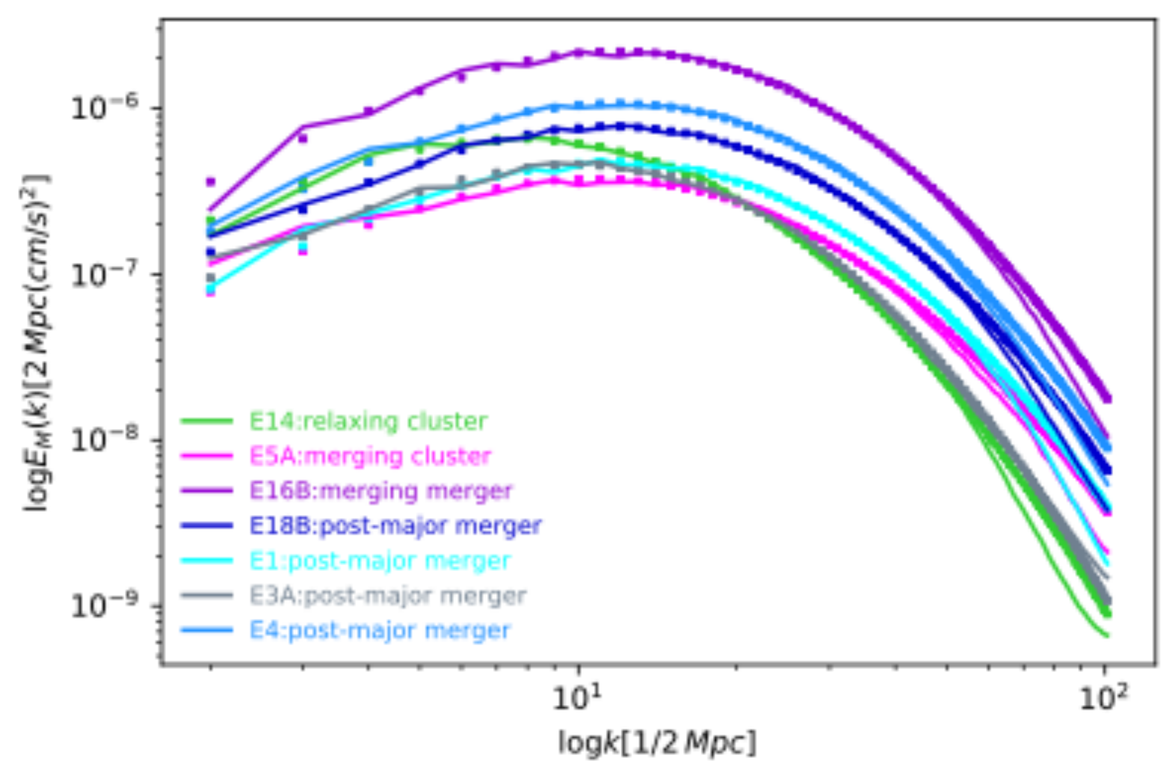
A → Normalization of the energy spectrum

C → Directly related to the peak of the spectrum

Results

1. Spectra fit in the cluster sample

Overview of magnetic energy spectra for our clusters at z=0. We computed the spectra at the highest resolution, 3.95 kpc in a box of 512^3 cells.



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1) The spectra are overall well fitted by the formula directly derived from dynamo theory regardless of the dynamical state of each cluster:

<u>Field components are *non-Gaussian* and the power spectra in general is *not* a power law</u>

2) The position of the peak of the spectrum gives us information about the dynamical state of the system:

$$k_{peak,relaxed} < k_{peak,merging}$$

In the presence of a small-scale dynamo:
<u>Equipartition is reached at larger scales once the system is relaxed.</u>

Simulation details:

- Initial conditions: z=30, B=0.1 nG
- MHD scheme: Dedner cleaning
- 2 nested IC + 6 AMR levels
- Maximum resolution: 3.95 kpc
- $M(r \leq 1.58\text{Mpc}) \sim 10^{14} M_{\odot}$

2. Spectral analysis for a merging system (E5A)

- We study the galaxy cluster E5A of the sample from z=1.379 to z=0.
- The dataset is reconstructed at the 6th AMR level (15.8 kpc resolution) for a faster analysis.
- We follow the evolution of the centre of the major component within a box of 100^3 cells

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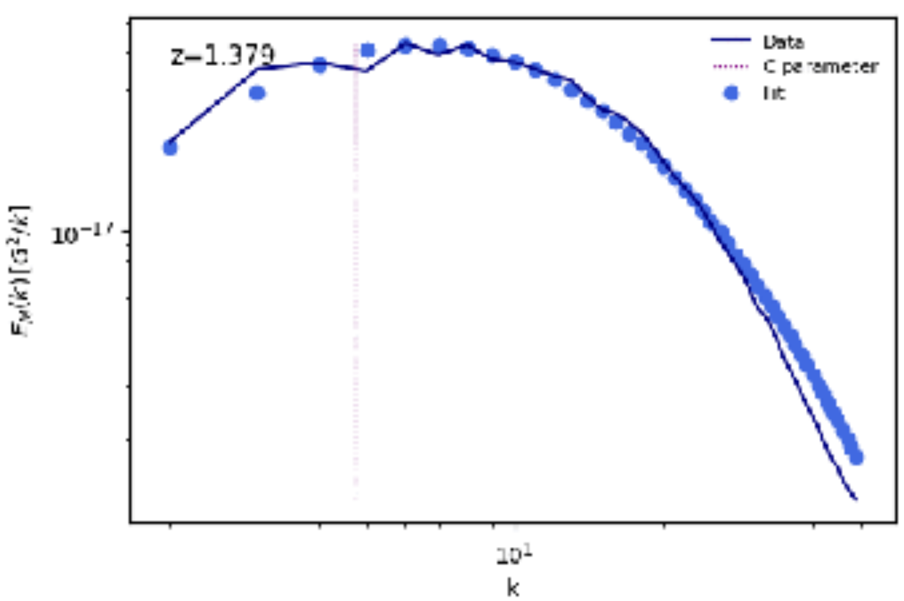
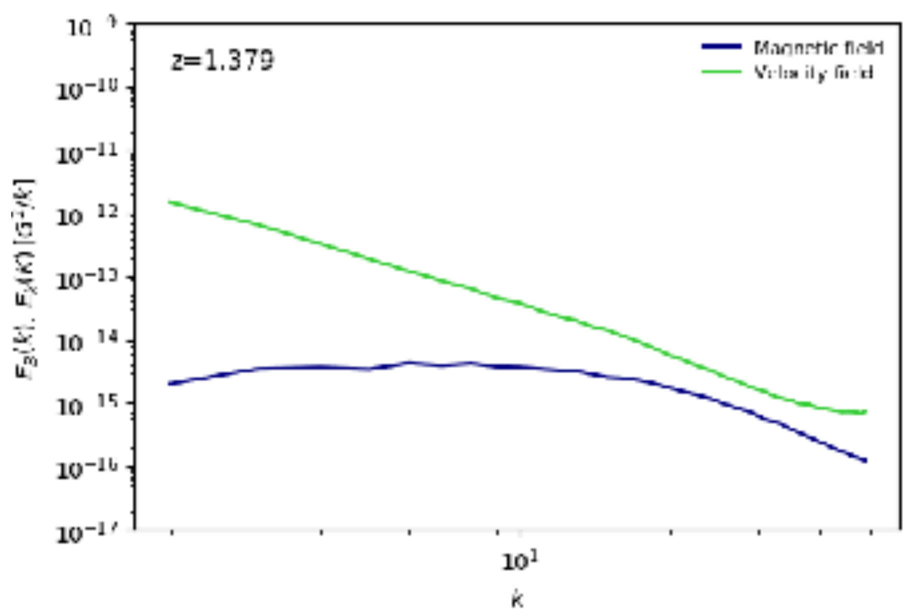
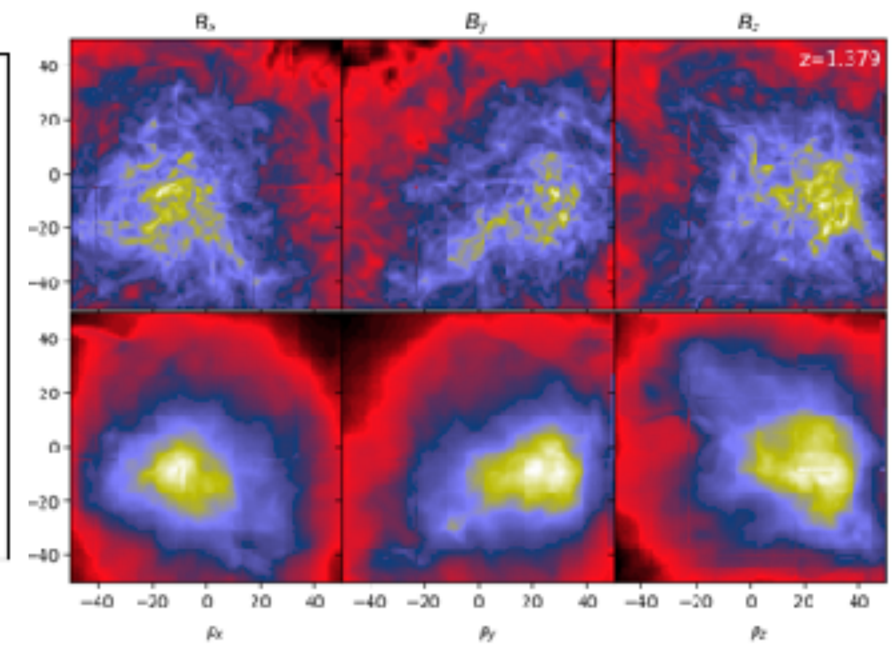
Fit of the magnetic energy spectrum



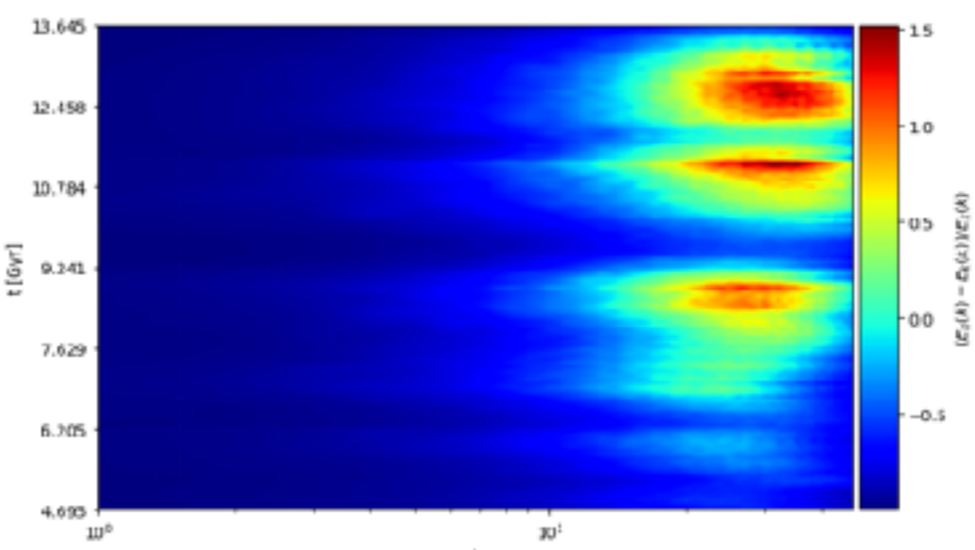
Magnetic and turbulent energy spectrum



Magnetic field and gas density



Time sequence map for difference between magnetic and kinetic energy

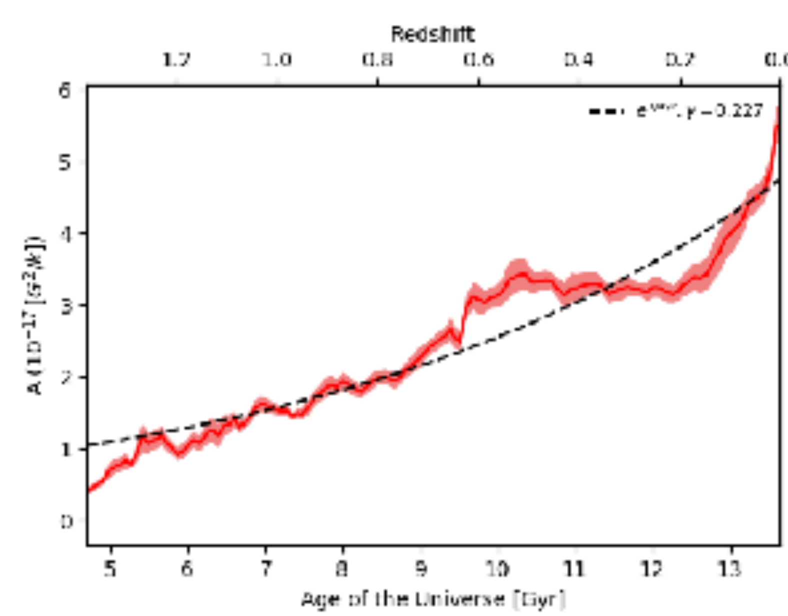


1) The strength of the magnetic fields relative to the kinetic pressure starts growing from small scales as suggested by dynamo theory.

2) We are able to identify the amplification periods. Mergers enhance the magnetic spectra, but quench the dynamo growth.

3) There is an overall exponential growth of the magnetic energy.

Normalization of the magnetic spectra



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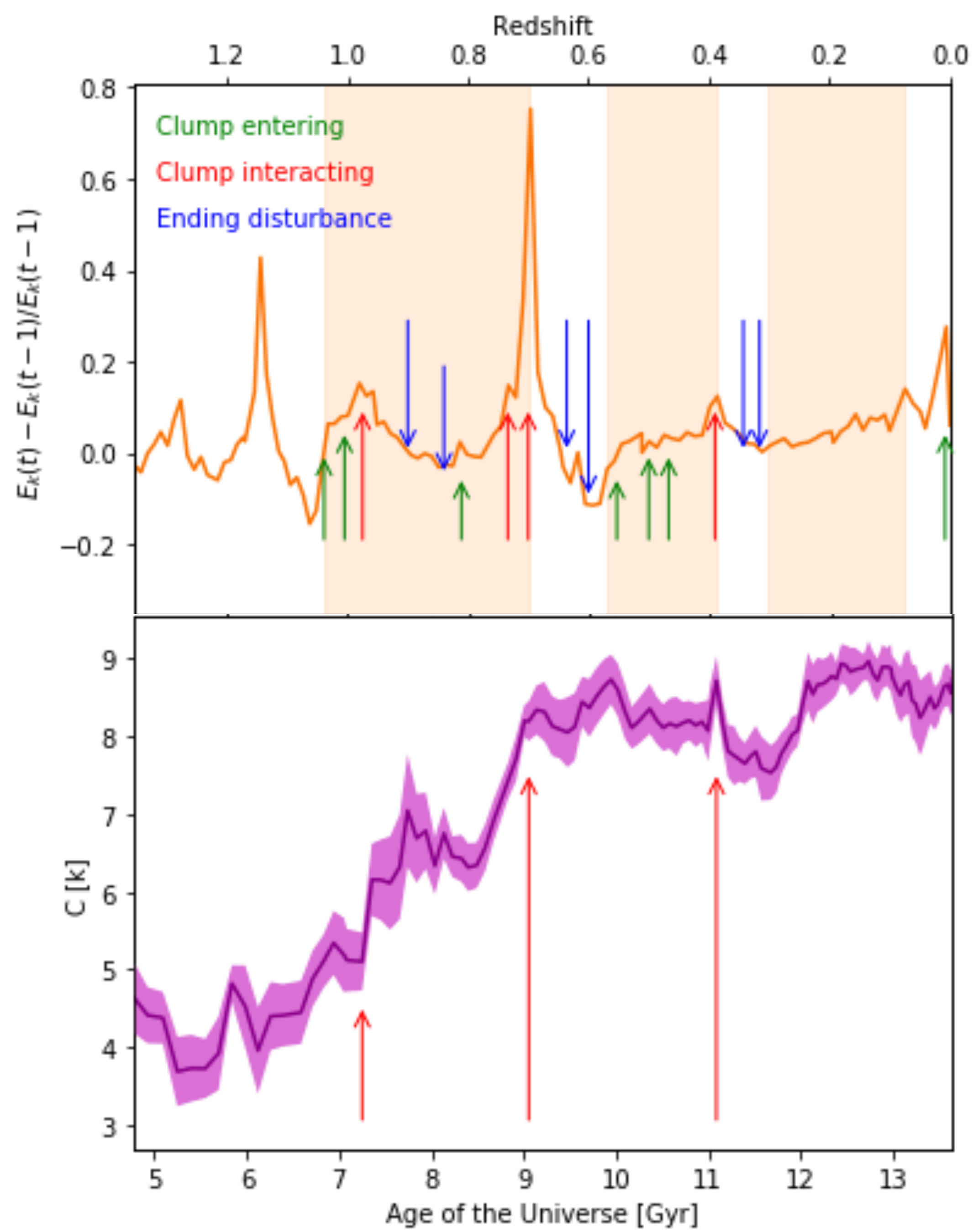

4) We investigate if *traveling shocks* are related to the shifts observed in the behaviour of the peak of the spectra. This can be directly related to the *size of infalling clumps*.

5) The amplitude and scales of the B-fields *depend* on the cluster formation epoch and on the last merger.

6) Observational consequences:

- Future surveys like SKA1 will greatly improve our understanding of the small topology of magnetic fields in galaxy clusters.
- Our results predict a non-Gaussian distribution of magnetic fields which should be visible in the distribution of RM.

References

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- Kulsrud R. M., Anderson S. w., 1992, Astrophysical Journal, 396, 606
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