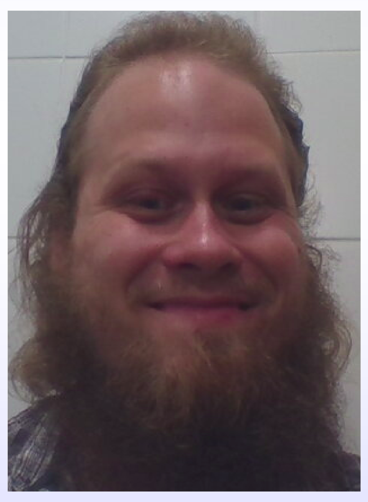

Propagation of UHECRs in the local Universe and the origin of cosmic magnetic fields.

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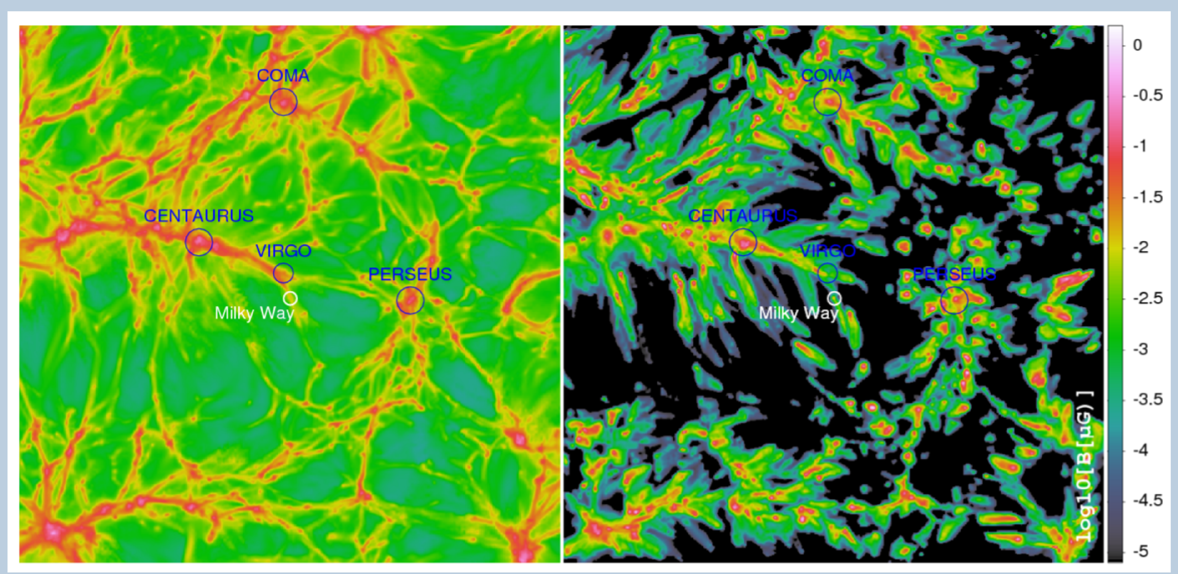
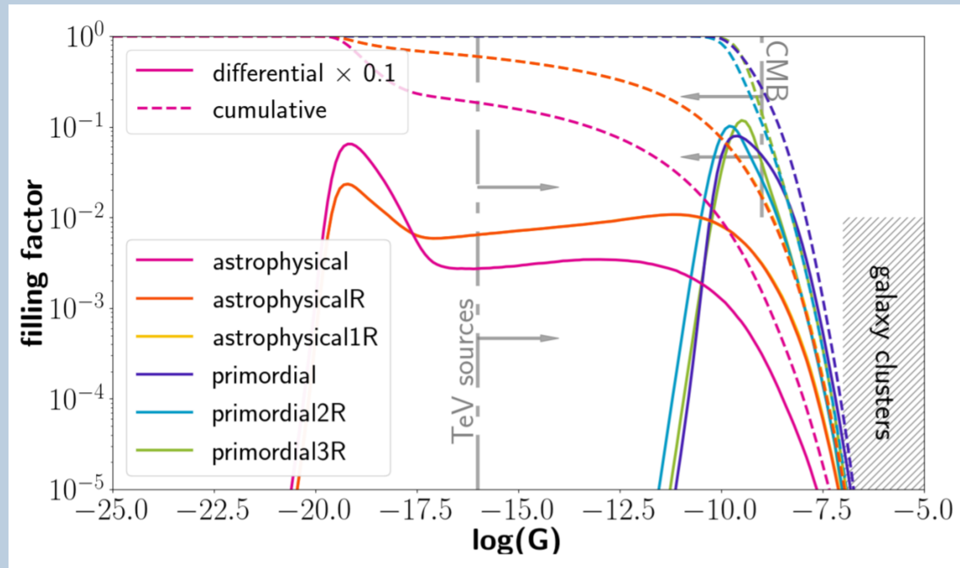
Introduction

We investigate constrained MHD simulations of the local Universe for different scenarios of magneto-genesis and their influence on the propagation of Ultra High Energy Cosmic Rays (UHECRs). We test different source models, ranging from dense to sparse distribution, in order to see what information on the extra-galactic magnetic field can be inferred, without exact knowledge of the sources of UHECRs. The MHD simulations have been performed with ENZO (http://www.enzo-project.org), which is an AMR code for cosmological simulations. The resulting magnetic field was used with the CRPropa (https://crpropa.desy.de/) to simulate the propagation of UHECRs. The observer is placed at the center of the simulation, where by definition is the position of the Milky Way.

Magnetic fields

We investigate two major scenarios for magneto-genesis: magnetic fields from primordial origin - prior to $z = 60$, where the MHD simulations start - for which we vary the spectral index of the initial power spectrum (more info in Hackstein et al. 2018). We compare this scenario to an astrophysical origin, modelled with thermal and magnetic feedback of AGN for several different redshift ranges. We improve on Dolag et al. 2003 by testing these different scenarios and by obtaining the expected B-ρ-ratio from a single consistent MHD simulation.

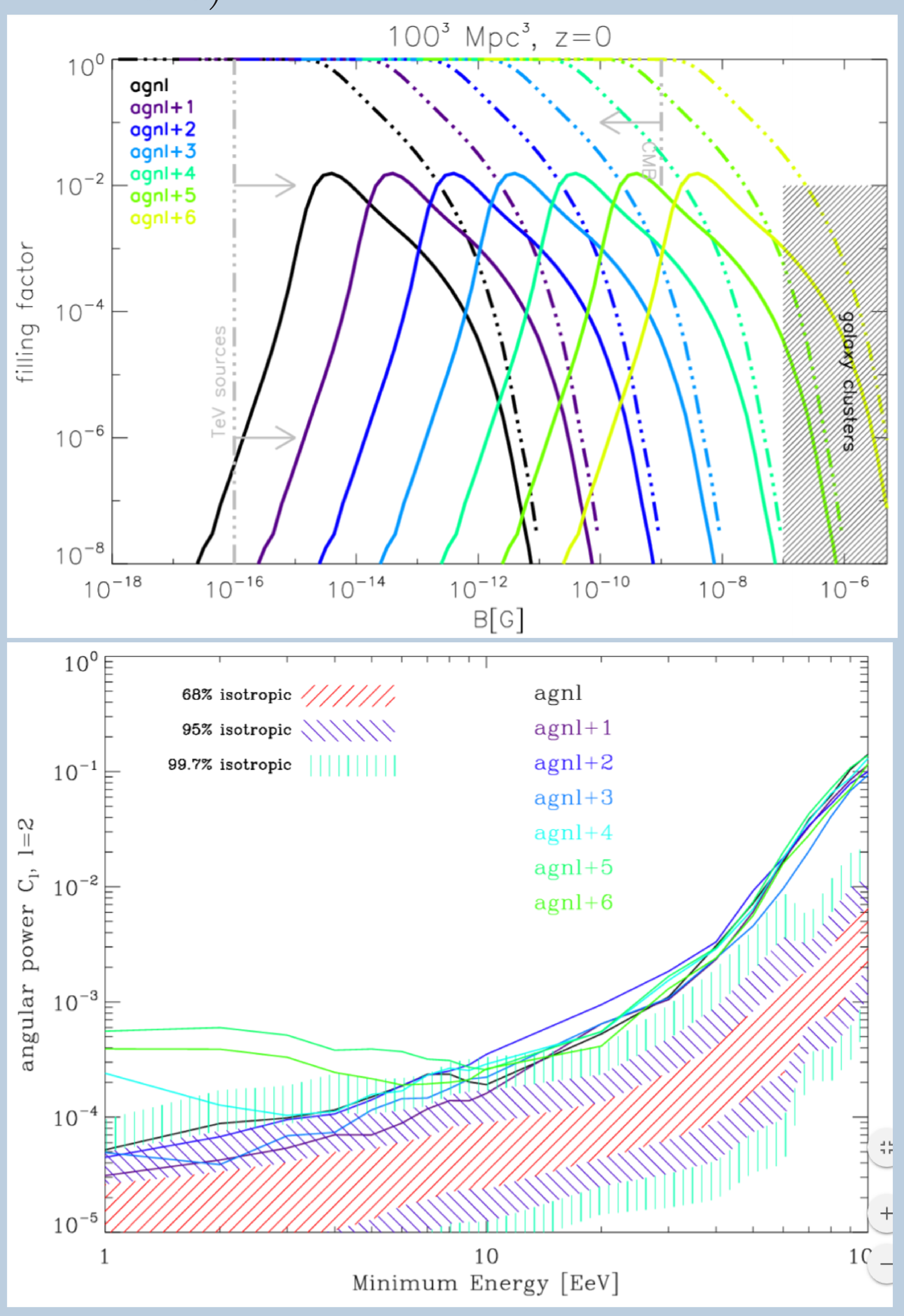




Both scenarios reproduce magnetic fields observed in clusters reasonably well. The main difference is that in the low-density regions, i. e. the voids, the magnetic field strength differs by up to 10 orders of magnitude. The two scenarios are therefore well suited to highlight the influence of the low-density regions.

Results II: Anisotropy

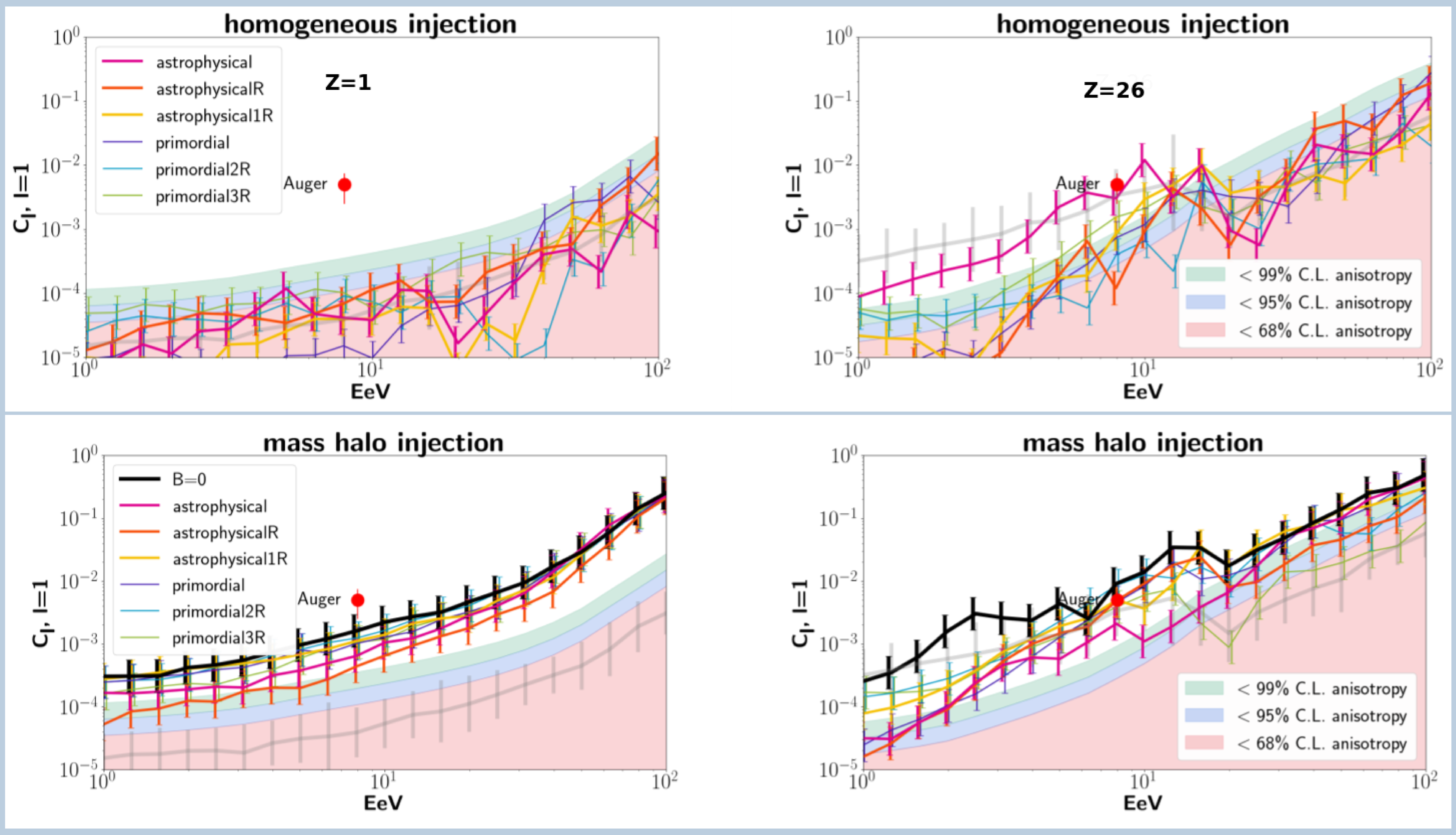
In another set of simulations we increased the strength of the magnetic field in voids step by step to see whether there are any effects of the fields in voids. The plots below show that for an increased magnetic field strength, anisotropy occurs at low energies, independent of the distribution of sources (results from Hackstein et al 2016).



In these simulations a uniform field dominates around the sources. In a semi-analytical model, one can show that anisotropy is indeed expected in that case. The same is also true for a dipolar and poloidal field and offers the chance to put limits on such structures in the halo of the Milky Way. If you want to learn more about this work in progress, let us talk about that!

Results I: Auger Dipole

Here we show the results for dipole angular power C_1. This is obtained by spherical decomposition of the full sky of observed UHECR events above the energy indicated in the x-axis. We compare two extreme source scenarios. In the upper two plots we consider homogeneous injection of UHECRs, i. e. no distinct sources. This scenario replicates the most isotropic incoming flux possible in a numerical simulation. For the lower plots we consider as sources the center of viral halos identified in the MHD simulation, where the most energetic objects are most likely to be found. This is right at the lower bound of allowed densities, $\gtrsim 10^{-4}$ Mpc^{-3}, as shown by di Matteo & Tinyakov 2017. The left panels show results for protons only, while the right panels consider a pure iron composition at injection. For comparison, the dipole observed in the Auger data > 8 EeV is also indicated.



Results for the different scenarios of magneto-genesis are pretty converged. This suggests that even right below the limit set by PLANCK CMB data, the fields in voids have minor influence on the large scale anisotropy signal of UHECRs. It is unlikely that we can identify magneto-genesis scenarios by full-sky observations of UHECR events without prior knowledge on their sources.

For light injection composition, a rather extreme source model is needed in order to reproduce the Auger dipole. The necessary sparsity of sources is right above, if not already below current limits. In contrast to that, due to multiple allowed hits of secondary nuclei of the same primary particle from a nearby source, the anisotropic contribution of the most nearby sources increases. This effect is the strongest at $E = E_{max}/A$, which is the maximum allowed energy for secondary protons and only protons from the most nearby sources may reach the observer.

Conclusion

1. light injection composition is unlikely to reproduce the Auger dipole while heavy injection increases multipoles.
2. uniform/dipole/poloidal fields can introduce anisotropy $\Rightarrow$ limit fields in MW halo