The impact of magnetic fields in the early accretion phase of massive primordial halos

Magnetic fields in massive primordial halos

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In Short

- *Motivation:* Magnetic fields, ubiquitous in the universe, can be amplified and significantly impact the dynamics of the gas that forms the first objects in the universe. Thus, their influence should not be overlooked.
- *Goals:* We will explore how amplified magnetic fields influence the early accretion phase of massive primordial halos, places where the seeds of supermassive black holes could form.
- *Methods:* We will conduct high-resolution, three-dimensional cosmological magneto-hydrodynamic simulations of massive primordial halos. These simulations will incorporate a detailed chemical network and we will vary three main parameters: the initial magnetic field strength, the UV radiation intensity and the Jeans resolution. In addition, we will use the pressure floor technique to continue evolving our halos for about 1 Myr, a necessary step to reach supermassive star formation.

The presence of numerous supermassive black holes (SMBHs) at very high redshift $(z \geq 6)$ [1] raises a fundamental question about the formation and nature of their seeds. The direct collapse of protogalactic gas clouds, in which hot, metal-free gas collapses under its own gravity to form a massive object of approximately $\sim 10^5$ M$_\odot$ [2] which then can grow through moderate accretion rates (~ 0.1 M$_\odot/yr$) [3] seems to be one of the most promising scenarios to form them. However, it is not yet known under what conditions a massive black hole can actually form. Several studies have shown the potential importance of magnetic fields during the formation of structures in the early Universe, as they can be amplified by gravitational compression and by the small-scale dynamo process in which turbulent energy is transformed into magnetic energy [4–6], so we can not ignore them. Most studies on the effect of magnetic fields on the formation of supermassive black holes in massive primordial halos were limited to a particular environment in which all simulated halos collapse isothermally due to strong Lyman-Werner radiation, which opens the need to explore more realistic scenarios in which molecular hydrogen (H$_2$, the main coolant in the early Universe) is also present. In [7] we explore how different environments affect the growth of magnetic fields in massive primordial halos of about 10^7 M$_\odot$ at redshift $z = 12$ through high-resolution zoom-in cosmological magnetohydrodynamical (MHD) simulations using the adaptive mesh refinement (AMR) code ENZO [8]. To follow the thermal and chemical evolution of the gas we use the KROME package [9]. In these simulations we vary the Lyman-Werner radiation intensity, the initial magnetic field strength and the Jeans length resolution, which is for resolving turbulent structures. Figure 1 shows the radial profile of the magnetic field strength, the magnetic field amplification $B/\rho^{2/3}$ and the relation between the magnetic and kinetic energy density for three different halos that differ in the initial radiation strength. We find that the effect of the UV background on the amplification of the magnetic field varies from halo to halo, however, regardless, the magnetic field is efficiently amplified by 7 to 10 orders of magnitude. This confirms that magnetic field amplification through the small-scale dynamo occurs over a wide range of conditions, both in the atomic ($J_{21} = 10^4, 10^5$) and molecular hydrogen ($J_{21} = 10^2, 10^3$) regimes. Now, how do these amplified magnetic fields in these different environments affect the gas dynamics and thus the masses of potential SMBH seeds and their accretion to grow? is the next question we want to answer. In the context of Population III (Pop III) star formation it has been shown that fragmentation differs significantly in simulations with and without magnetic fields, thus concluding that magnetic fields have a significant impact on the IMF of these stars, but studies showing what the actual impact on the initial mass function (IMF) of the first stars looks like yield contradictory results that remain unclear. It has recently been shown that magnetic fields can enhance star formation by helping to cool the gas and give rise to low-mass Pop III stars [10], but, on the other hand, other work shows the opposite, where magnetic fields suppress star formation, due to the magnetic pressure stabilising the disc, thus leading to a top-heavy IMF [11]. Therefore, similar to our previous research and changing the same parameters, we plan to perform 3D cosmological MHD simulations from which we will search for a massive halo and evolve it using the pressure floor technique to avoid collapse on smaller scales. Using this method, we will evolve our simulations for ~ 1 Myr at the onset of collapse, comparable to the lifetime of a supermassive star.

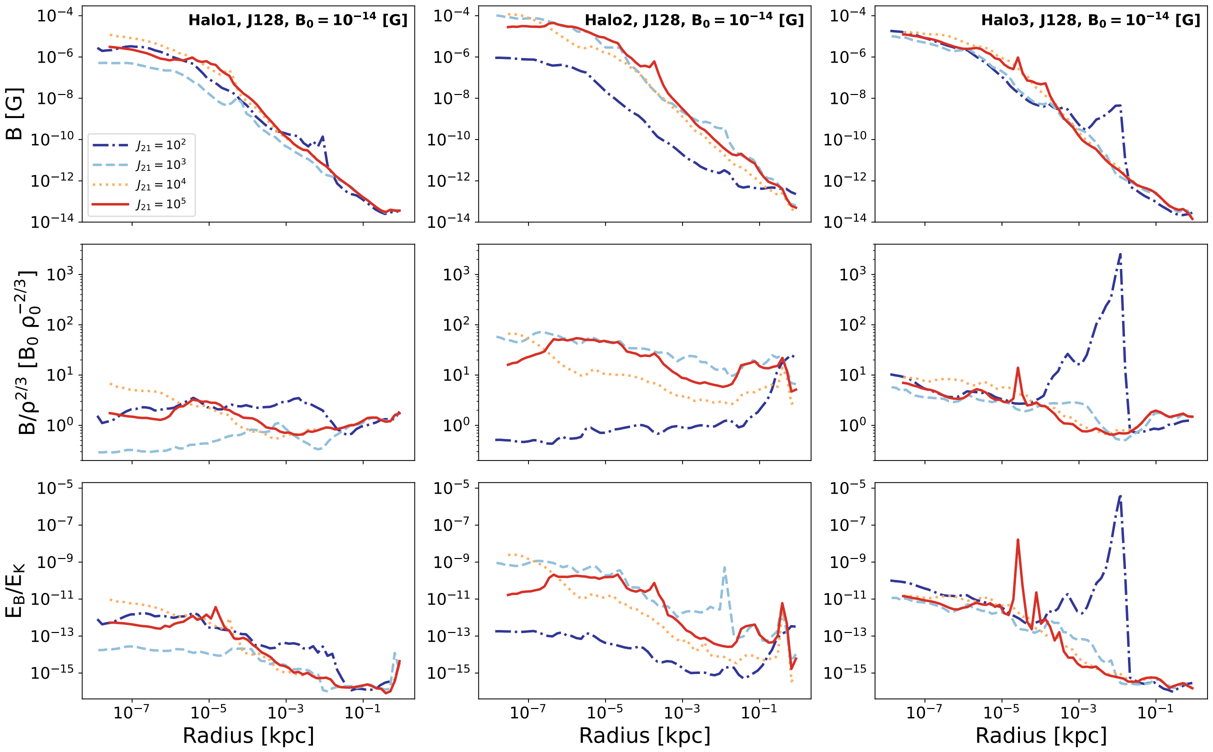

Figure 1: *Mass-weighted spherically binned radial profiles of magnetic field strength, magnetic field amplification $B/\rho^{2/3}$, and the magnetic-to-kinetic energy density ratio E_B/E_K for the three different halos when reaching a peak density of $3 \times 10^{-13}\ g/cm^3$ using a fixed Jeans resolution of 128 cells and $B_0 = 10^{-14}$ [G] (proper). The first, second, and third column of this multiple plot shows the magnetic properties of halo 1, halo 2, and halo 3, respectively. The dash-dotted blue line is for $J_{21} = 10^2$, the dashed light blue line is for $J_{21} = 10^3$, the dotted orange line is for $J_{21} = 10^4$, and the solid red line is for $J_{21} = 10^5$. Figure from Díaz et al. (2024) [7].*

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https://www.physik.uni-hamburg.de/en/hs/subsite---research/research-banerjee-redirect.html

More Information

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