Magnetic fields and the birth of the first quasars

Magnetic fields in massive primordial halos

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In Short

- *Motivation:* Recent studies have shown that magnetic fields can be amplified in the early Universe, affecting the dynamics of the gas from which the first objects can be formed, therefore its effect should not be ignored.
- *Goals:* We will study the magnetic field amplification on large scales in the places where the first quasars formed.
- *Methods:* We will perform high-resolution cosmological three-dimensional magneto-hydrodynamic simulations of primordial halos that could potentially form a quasar at z=6 with different initial magnetic field strengths.

The discovery of more than 200 quasars at redshift greater than 6 shows that the supermassive black holes (SMBHs) that powered them were already in place during the first billion years after the Big Bang [1]. How the seeds of these massive objects formed and how is the environment where they lived and grew is still under debate and therefore an open question in astrophysics. Several scenarios have been proposed to explain the formation of these seeds, such as remnants of the first generation of stars formed out of pristine gas, run-away collisions in dense stellar clusters and the direct collapse of protogalactic gas clouds in which the massive object forms because the warm and metal-free gas collapses under its own gravity [2]. The direct collapse scenario seems to be the most promising scenario as it yields to the most massive black hole seeds which can then grow through moderate accretion rates [3], however, to reach those moderate mass inflow rates with this pathway we need to keep the gas warm to avoid fragmentation, this means we need the presence of a strong UV background to suppress the formation of molecular hydrogen, which is the main coolant of the early Universe [4].

In addition, previous studies have shown that the quasars observed at high redshift can form if the halos where the MBH seeds formed are fed by cold, dense accretion flows and recently [5] showed that these flows from large scale generates high supersonic turbulence that helps to prevent star formation by allowing the halo to grow without the presence of UV radiation, atomic cooling or streaming motions eliminating the uncertainties that this adds to the direct collapse scenario.

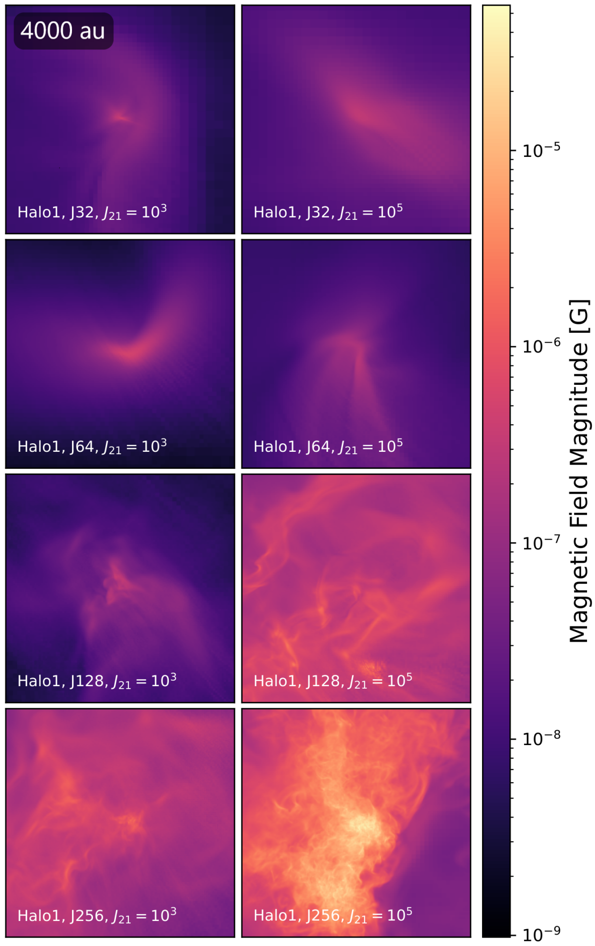

Figure 1: *Density-weighted projection of magnetic field magnitude along the z-axis with a physical width of 4000 au for Halo 1 when reaching a peak density of 3×10^{-13} g/cm^3 using 32, 64, 128 and 256 cells per Jeans length, $J_{21} = 10^5$ and 10^3 and an initial magnetic field of $B_0 = 10^{-14}$ G (proper).*

Most of the studies about SMBH and quasar formation have not included the effect of magnetic fields which are ubiquitous in the Universe and although they are known to be weak in the early Universe, it has been shown that they can grow on small scales through the small-scale dynamo, which transform turbulent energy into magnetic energy, and thus affect the dynamics of the gas as they can suppress fragmentation by adding additional magnetic pressure [6–9]. This clearly indicates that we cannot ignore their effect when studying the formation of the first objects in the Universe.

In the first phase of our project we studied how

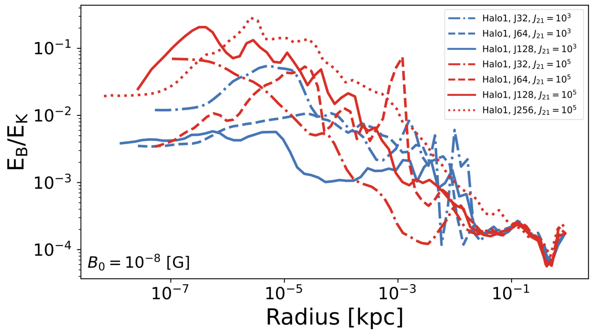

***Figure 2:** Mass-weighted spherically binned radial profile of the magnetic to kinetic energy ratio for Halo 1 when reaching a peak density of 3×10^{-13} g/cm^3 using 32, 64, 128 and 256 cells per Jeans length, $J_{21} = 10^5$ and 10^3 and an initial magnetic field of $B_0 = 10^{-8}$ G (proper).*

different environments affect the growth of magnetic fields in primordial massive halos by varying the intensity of the UV background to explore the amplification of magnetic fields in both the atomic cooling and molecular hydrogen cooling regimes. Similar to previous studies, we found that a weak initial magnetic field seed can be efficiently amplified through the small-scale dynamo for sufficiently high resolution per Jeans length, as shown in Figure 1, where the strongest magnetic fields were typically obtained for simulations with the highest Jeans resolution. This occurs independently of the UV flux intensity, indicating that magnetic fields on small scales can be amplified over a wide range of conditions and therefore in different environments. By using stronger initial magnetic field seeds, we found that the halos where the cooling is driven by molecular hydrogen saturate at a lower initial magnetic field strength compared to the halos where the atomic cooling dominates. In Figure 2 shows how the ratio between the magnetic (E_B) to kinetic (E_{kin}) energy density for the simulations using our strongest initial magnetic field seed decreases towards the centre in some cases reaching a value of $E_B/E_{kin} \sim 0.1$ which is a clear indication that the magnetic field is almost reaching the saturation state. Moreover, studies of first stars formation have shown that a large-scale dynamo can also operate when a self-gravitating disk is formed, hence it will be important to study the subsequent evolution of the places where these massive seeds that powered the first quasars formed, as it is not entirely clear how the large scale magnetic field grows in these turbulent environments generated by the presence of cold accretion flows.

The main goal of this work is to study the large-scale magnetisation of the medium where the first quasars form. We want to know how it grows in these turbulent environments before the halo forms and after this process at different stages of the collapse to identify whether a large-scale dynamo exists in these sites. Additionally, we want to study the saturation of these amplified magnetic fields on large scales. To achieve our goals we are going to perform 18 high-resolution cosmological magneto-hydrodynamical simulations with the adaptive mesh refinement (AMR) code ENZO [10] by employing different initial magnetic field seeds and different Jeans resolutions.

WWW

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

More Information

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