Supermassive black hole formation and the effect of magnetic fields in atomic cooling halos

Magnetic fields in massive primordial halos

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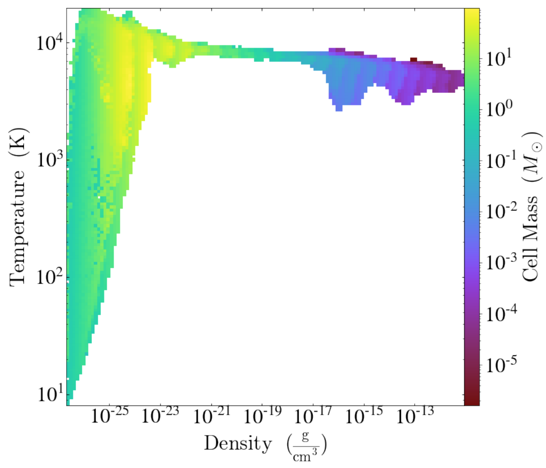

***Figure 1:** Phase plot (temperature against density) of the most massive halo in a cosmological simulation with $J_{21} = 10^5$.*

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 in atomic cooling halos and its impact on the supermassive black hole formation in different environments.
- *Methods:* We will perform high-resolution cosmological three-dimensional magneto-hydrodynamic simulations of massive primordial halos including a detailed primordial chemical model.

Numerous quasars with masses of about 10^9 M$_\odot$ at very high redshift $(z \geq 6)$ have been discovered through many surveys in the last years [1]. The discovery of these massive objects raises a fundamental question about the formation and nature of their seeds in the Universe. These seeds, formed at very high redshift, may grow via merging or accretion to reach the high masses of the supermassive black holes (SMBHs) that we see today. The models that have been proposed to explain the formation of these objects include the merging and accretion of Population III (Pop III) remnants formed out of pristine gas, run-away collision in dense stellar clusters which suffer run-away collisions growing into a single massive star and the direct collapse of protogalactic gas clouds, where warm and metal-free gas collapses under its own gravity forming a massive object [2]. The direct collapse is the SMBH formation path that provides the most massive black hole seeds ($\sim 10^5$ M$_\odot$) which then can grow through moderate accretion rates (~ 0.1 M$_\odot/yr$) [3], therefore, it potentially seems to be the most promising scenario to create a SMBH. The cradles for the direct collapse black hole (DCBH) formation are called atomic cooling halos which are very massive halos of about $10^7 - 10^8$ M$_\odot$ where a strong UV background suppresses the main coolant of the early Universe, the molecular hydrogen (H_2), keeping the gas warm favoring high accretion rates and therefore suppressing fragmentation [4].

Figure 1 shows the density-temperature phase plot of a very massive halo irradiated by a strong radiation background ($J_{21} = 10^5$) from which we can see that the gas collapses isothermally with a temperature of about 8000 K due to the suppression of H_2 cooling. J_{21} denotes the available flux from star-forming regions where $J_{21} = 1$ corresponds to a flux of 10^{-21} erg cm^{-2} s^{-1} Hz^{-1} sr^{-1} at the Lyman limit. Although the formation of supermassive black holes has been studied through different models, it is not yet understood under what conditions a massive black hole can really be formed.
Moreover, previous studies have shown that in the early Universe weak magnetic field seed can be formed and efficiently amplified through the small-scale dynamo process, which transforms the turbulent energy into magnetic energy at early stages subsequently affecting the dynamics of the halos by helping in suppressing fragmentation via additional magnetic pressure [5,6]. This indicates that in the context of the formation of the first objects the effect of the magnetic fields cannot be ignored.
Additionally, in [7] we were able for the first time to include a magnetohydrodynamical subgrid scale (SGS) model for unresolved turbulence finding that in the presence of strongly amplified magnetic fields intermittent fragmentation occurs during the collapse of atomic cooling halos with accretion rates sufficiently large to support the direct collapse scenario.
Most of these studies are limited to one particular

environment in which all the simulated halos collapse isothermally due to the high UV background applied, opening the necessity of exploring a larger variety of halos with different and more realistic environments to have a better understanding of the places in which a SMBH can be formed.

The main goal of this project is to investigate how different environments affect the growth of magnetic fields in the primordial massive halos. To do so, we will use the 3D MPI-parallel, adaptive mesh refinement (AMR) code ENZO [8] to perform high-resolution zoom-in cosmological magneto-hydrodynamical simulations in which we will find the most massive halo ($10^7 - 10^8$ $M_\odot$) at redshift $z = 12$ to follow its evolution and magnetic field amplification. Furthermore, we will include a detailed chemistry model through the open-source chemistry package KROME [9] to solve the chemical and thermal evolution of the gas. We will include a UV background varying its strength from $J_{21} = 10^2$ to $J_{21} = 10^5$ using a realistic spectrum with a temperature of $T_{rad} = 2 \times 10^4$ K aiming to explore, for the first time, the magnetic field amplification in environments including the effect of H_2 cooling as expected in almost all realistic scenarios. Additionally, we will vary the initial magnetic field strength between 10^{-14} to 10^{-10} G (proper), and to resolve turbulent structures and small-scale dynamo effect, we will employ a high Jeans resolution (64, 128 and 256 cells) as in atomic cooling halos the Jeans length needs to be resolved by at least 64 cells and in some cases is necessary an even higher resolution to fully resolve magnetic fields [5,7]. Moreover, with this project, we plan to follow the evolution of halos with smaller masses and different spins to study their effects on the magnetic field amplification.

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https://www.physik.uni-hamburg.de/en/hs/group-banerjee.html

More Information

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Project Partners

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