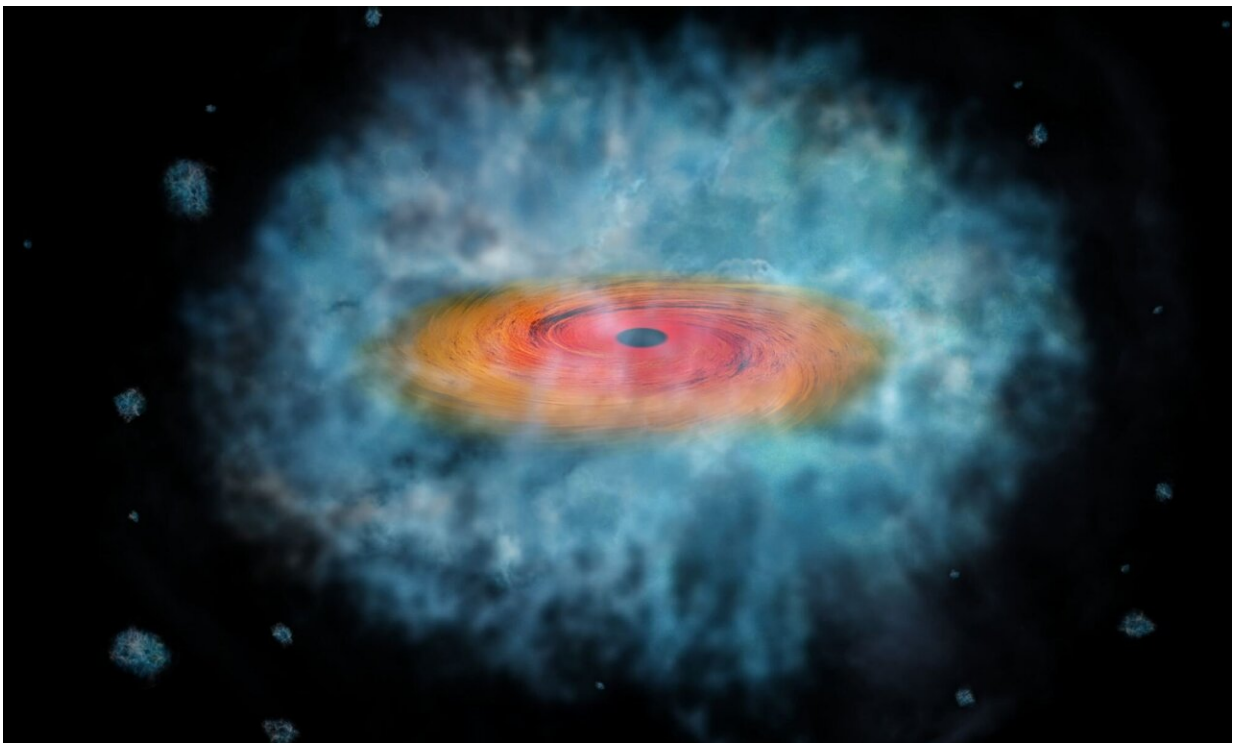


# Did supermassive black holes collapse directly out of giant clouds of gas? It could depend on magnetic fields

November 1 2022, by Matt Williams

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This artist's impression shows a possible seed for the formation of a supermassive black hole. Credit: NASA/CXC/M. Weiss

Roughly a half-century ago, astronomers realized that the powerful radio source coming from the center of our galaxy (Sagittarius A\*) was a

"monster" black hole. Since then, they have found that supermassive black holes (SMBHs) reside at the center of most massive galaxies. This leads to what is known as Active galactic nuclei (AGN) or quasars, where the central region of a galaxy is so energetic that it outshines all of the stars in its galactic disk. In all that time, astronomers have puzzled over how these behemoths (which play a crucial role in galactic evolution) originated.

Astronomers suspect that the seeds that formed SMBHs were created from giant clouds of dust that collapsed without first becoming stars—aka, Direct collapse [black holes](#) (DCBHs). However, the role of magnetic fields in the formation of DCBHs has remained unclear since none of the previous studies have been able to simulate the full accretion periods. To investigate this, an international team of astronomers ran a series of 3D cosmological magneto-hydrodynamic (MHD) simulations that accounted for DCBH formation and showed that magnetic fields grow with the accretion disks and stabilize them over time.

The research was led by Muhammad A. Latif, an assistant professor of physics at the College of Science at United Arab Emirates University (UAEU). He was joined by associate professor Dominik R. G. Schleicher of the Universidad de Concepcion in Chile and Sadegh Khochfar—the personal chair of Theoretical Astrophysics at the University of Edinburgh and the Royal Observatory. The paper that describes their findings recently appeared online on the preprint server *arXiv* and is currently being reviewed for publication in *The Astrophysical Journal*.

As they indicate in their paper, DCBHs are high-mass black hole seeds (typically around 1 million [solar masses](#)) that existed in the early universe—ca. 100 to 250 million years old. As the name suggests, DCBHs are formed directly from massive clouds of dust and gas (due to instabilities predicted by Einstein's theory of general relativity). This sets

them apart from black holes that originated from the earliest supermassive stars (SMSs), also known as Population III stars. As Dr. Latif told Universe Today via email, astrophysicists have long suspected that these may be how SMBHs formed in the [early universe](#):



According to recent studies, early stars (Population III) were not the only source of primordial black holes. Credit: NASA/WMAP Science Team

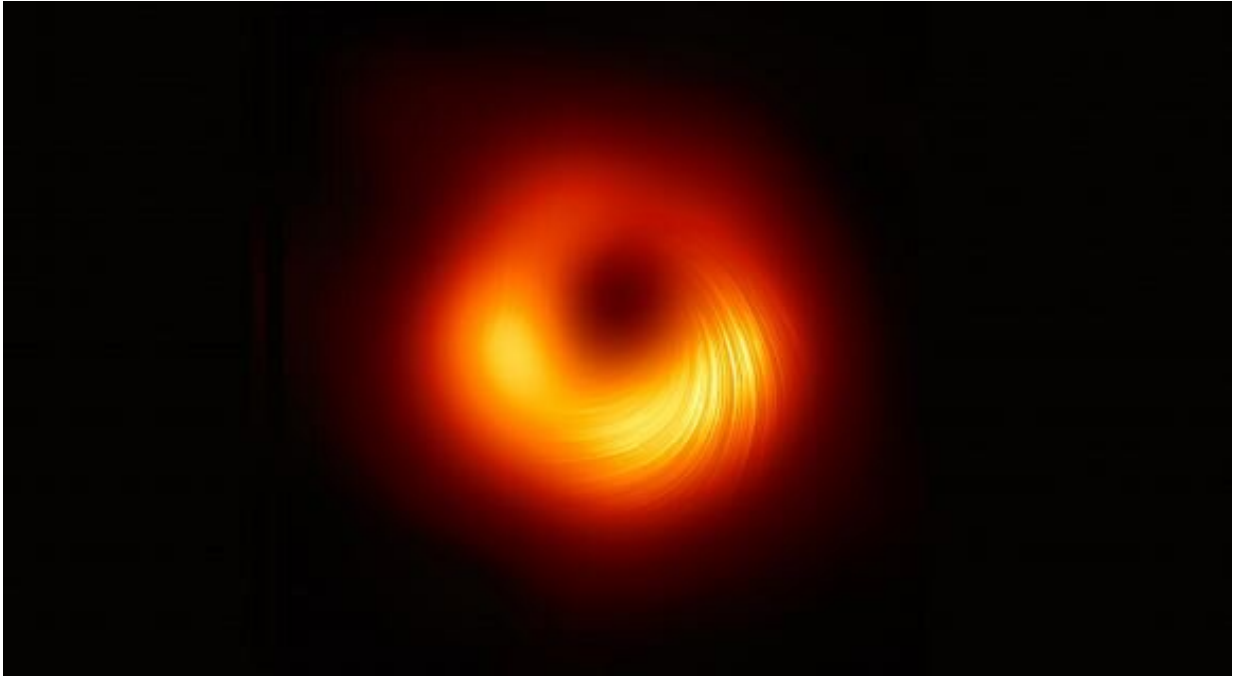
"DCBHs are about two orders of magnitude more massive ( $10^5$  solar mass) than black holes from other scenarios, such as stellar mass black holes (about 100 solar mass) or black holes forming via stellar collisions (~1000 solar mass). This makes them leading candidates, particularly for the first SMBHs observed within the first Gyr after the Big Bang."

The existence of SMBHs was originally proposed to explain the

existence of high-redshift primordial SMBHs that existed within 1 billion years after the Big Bang. But as Latif and his colleagues explain, there were inconsistencies between what astrophysicists theoretically predicted and what astronomers have observed. In particular, there's the role that magnetic fields played in the accretion of material with primordial dust clouds, which eventually resulted in gravitational collapse and the formation of DCBHs.

"The standard model of physics does not provide any constraints on the initial [magnetic field](#) strength, and some models predict small B-fields of the order of  $10^{-20}$  G," said Latif. "They are about many orders of magnitude smaller than observed fields (about 1G). Therefore, the scientific community thought that their role might be only secondary."

This mystery has persisted because previous attempts to simulate the formation of DCBHs numerically have been limited in scope. Previous simulations have lacked the computing power to simulate the accretion process's full length, which is considered comparable to the expected lifetime of SMSs—1.6 million years. Thanks to advances in supercomputing during the past decade, different research groups have conducted numerical simulations in the past decade that show that magnetic fields can be amplified within a short period.



This view of the M87 supermassive black hole in polarized light highlights the signature of magnetic fields. Credit: EHT Collaboration

Similarly, there's increasing evidence that magnetic fields were present roughly 13 billion years ago when DCBHs are expected to have formed. To address this mystery, Latif and his colleagues conducted a series of 3D cosmological magneto-hydrodynamic (MHD) models that accounted for a lifetime of 1.6 million years:

"We model accretion onto the central clump forming in our simulation, which is a proxy for a protostar. We evolve simulations for about 1.6 Myr, comparable to the expected lifetime of SMSs, and calculate how much mass accumulates onto the clump, which tells us the accretion rate. Previous works evolved simulation only for short time up to a kyr (1000 years) which is much shorter than the lifetime of SMSs (~2 million years). Therefore, it is important to know whether accretion can be

sustained for long enough, which we show that it is possible."

Their findings are consistent with previous research by Latif and his colleagues (and other groups) that show how magnetic fields play a vital role in the formation of massive stars and black holes. These studies have shown how magnetic fields are amplified (increase in Jean mass) by accreting disks of gas and dust. These fields are responsible for reducing fragmentation and stabilizing the disks, eventually allowing these disks to achieve the mass necessary (aka. Jean mass) to experience gravitational collapse and form supermassive stars and black holes.

"Such strong magnetic fields can even launch jets and outflows and also help in transporting angular momentum, which is considered an obstacle for forming stars," explained Latif. "Therefore, they will have important implications for the magnetization of interstellar and intergalactic mediums (similar to what we observe in the local universe) and shaping the formation of high redshift galaxies as well as the evolution of massive black holes."

These findings also preview what future studies could reveal about magnetic fields and their role in the formation and evolution of early galaxies. In the coming decade and after, astronomers are expected to study the jets and outflows of the earliest [black holes](#) using powerful radio observatories like the Square Kilometer Array (SKA) and next-generation Very Large Array (ng-VLA)—which are expected to become operational by 2027 and 2029 (respectively).

**More information:** Muhammad A. Latif et al, Role of magnetic fields in the formation of direct collapse black holes, *arXiv* (2022). [DOI: 10.48550/arxiv.2210.05611](https://doi.org/10.48550/arxiv.2210.05611)

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