Stampede2 supercomputer simulates star seeding, heating effects of primordial black holes

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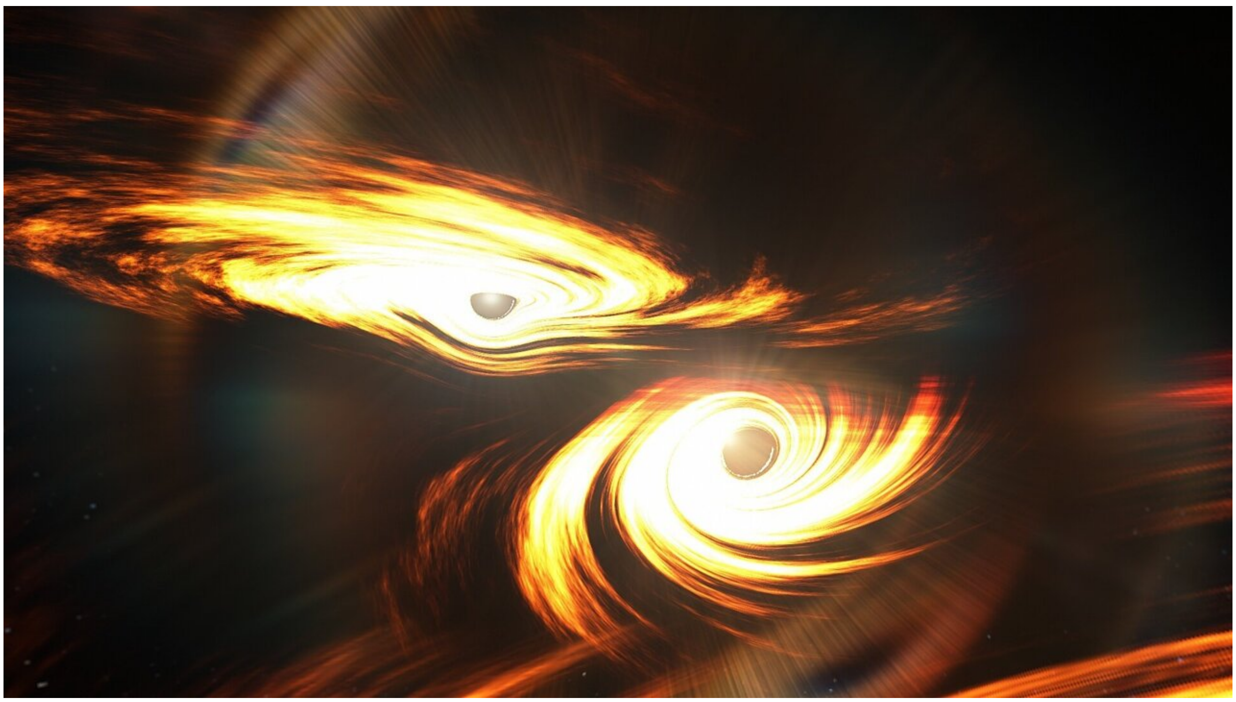


Supercomputer simulations have probed primordial black holes and their effects on the formation of the first stars in the universe. Black holes can help stars form by seeding structures to form around them through their immense gravity. They also hinder star formation by heating the gas that falls into them. XSEDE-allocated Stampede2 simulations show these effects basically cancel each other out. Shown here is an artist's concept that illustrates a hierarchical scheme for merging black holes. Credit: LIGO/Caltech/MIT/R. Hurt (IPAC)

Just milliseconds after the universe's Big Bang, chaos reigned. Atomic nuclei fused and broke apart in hot, frenzied motion. Incredibly strong pressure waves built up and squeezed matter so tightly together that black holes formed, which astrophysicists call primordial black holes.

Did primordial black holes help or hinder formation of the universe's first stars, eventually born about 100 million years later?

Supercomputer simulations helped investigate this cosmic question, thanks to simulations on the Stampede2 supercomputer of the Texas Advanced Computing Center (TACC), part of The University of Texas at Austin.

"We found that the standard picture of first-star formation is not really changed by primordial black holes," said Boyuan Liu, a post-doctoral researcher at the University of Cambridge. Liu is the lead author of computational astrophysics research published August 2022 in the *Monthly Notices of the Royal Astronomical Society*.

In the early universe, the standard model of astrophysics holds that black holes seeded the formation of halo-like structures by virtue of their gravitational pull, analogous to how clouds form by being seeded by dust particles. This is a plus for star formation, where these structures served as scaffolding that helped matter coalesce into the first stars and galaxies.

However, a black hole also causes heating by gas or debris falling into it. This forms a hot accretion disk around the black hole, which emits energetic photons that ionize and heat the surrounding gas.

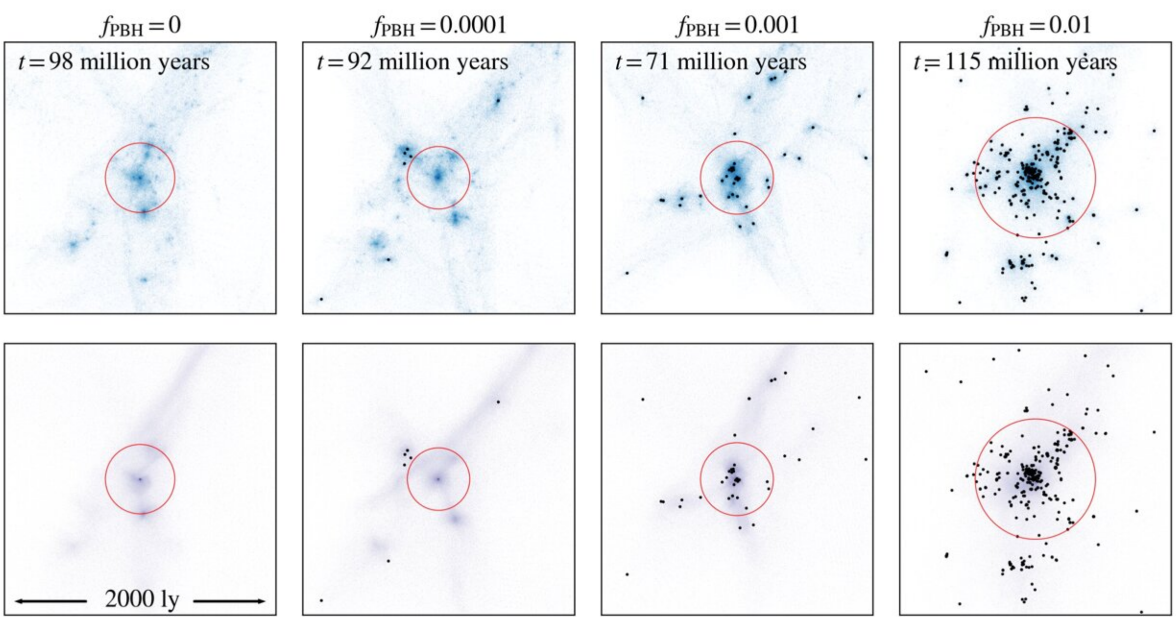
And that's a minus for star formation, as gas needs to cool down to be able to condense to high enough density that a nuclear reaction is triggered, setting the star ablaze.

"We found that these two effects—black hole heating and seeding—almost cancel each other out and the final impact is small for star formation," Liu said.

Depending on which effect wins over the other, star formation can be accelerated, delayed or prevented by primordial black holes. "This is why primordial black holes can be important," he added.

Liu emphasized that it is only with state-of-the-art cosmological simulations that one can understand the interplay between the two effects.

Regarding the importance of primordial black holes, the research also implied that they interact with the first stars and produce gravitational waves. "They may also be able to trigger the formation of supermassive black holes. These aspects will be investigated in follow-up studies," Liu added.



Matter fields at the moment of cloud collapse (i.e. onset of star formation) as projected distributions of dark matter (top) and gas (bottom) in four simulations targeted at the same region but with different abundances of primordial black holes, measured by the parameter f_PBH. Primordial black holes are plotted with black dots and the circles show the size of the structure that hosts the collapsing cloud. The data slice has a physical extent of 2000 light years and a thickness of 1000 light years. The age of the universe at the moment of collapse first decreases with f_PBH for f_PBH