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Quasars, black holes, and a cosmological conundrum

A quest for the origin of the most-distant quasars in the early universe

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UNIVERSITY PARK, Pa. — Astrophysicist Yuexing Li's quest began with quasars, luminous galaxies powered by supermassive black holes actively devouring matter and releasing enormous amounts of electromagnetic radiation so hot and bright we can see it more than 13 billion light years away.

These colossal objects, formed less than a billion years after the Big Bang during a period called the Cosmic Dawn, have fascinated Li since she was a postdoc at Harvard, where she was on the team that first modeled the formation of what was then the most distant known quasar.

"The most puzzling thing about these distant quasars," she said, "is how did the supermassive black holes at their hearts form? Because they're thought to weigh more than a billion suns, these black holes' existence so early in the universe is difficult for us to explain with our theoretical models."

The best-understood way black holes form is by the gravitational collapse of massive dying stars, which produces so-called stellar-mass black holes, with masses less than 100 times that of our sun.

These black holes may grow more massive by merging with other black holes and through a process called accretion, where surrounding matter is were required, how could they possibly have formed?"

Critical conditions

In cosmological simulations, there's an inherent trade-off between resolution (fineness of detail) and scale (relative size), and Li — now an associate professor of astronomy and astrophysics at Penn State — believes that trade-off may be the crux of the problem.

"A major problem with previous studies is that macroscale cosmological simulations do not have sufficient resolution to resolve the critical microscale physics of black hole growth," she explained.

So Li developed a novel solution — combining large-scale simulations with small-scale simulations of ultrahigh resolution that would allow her to better model the formation and growth of small black holes in the early universe.

"With the unprecedented resolution of these new simulations," she said, "I realized that some conclusions from previous papers may be only part of the story."

Li had found the critical conditions under which those small black holes' rate of accretion could exceed the standard limit, accelerating to what's called super-Eddington accretion.

With ART2 running on Penn State's ROAR supercomputer, she can use her simulations to determine the likely observational properties of those first quasars, which she can then compare with existing data to make predictions for next-generation instruments like the James Webb Space Telescope (JWST).

"This is a very important step to bridge the gap between simulation and observation," she explained.

Using ART2, Li predicts that JWST, launched in November 2021, will be able to detect galaxies less than 300 million years after the Big Bang — pushing the cosmic frontier to an earlier epoch than ever before.

But even JWST, NASA's most ambitious telescope, won't be able to see electromagnetic radiation from small black holes at the Cosmic Dawn.

So Li is collaborating with Penn State's LIGO group, studying gravitational waves — ripples in space-time — produced when black holes collide and merge.

"When those small black holes merge," she explained, "the resulting gravitational waves, whose frequencies fall outside of the detection range of current ground-based observatories like LIGO, will be detectable by future observatories like LISA, the space-based gravitational-wave detector."

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