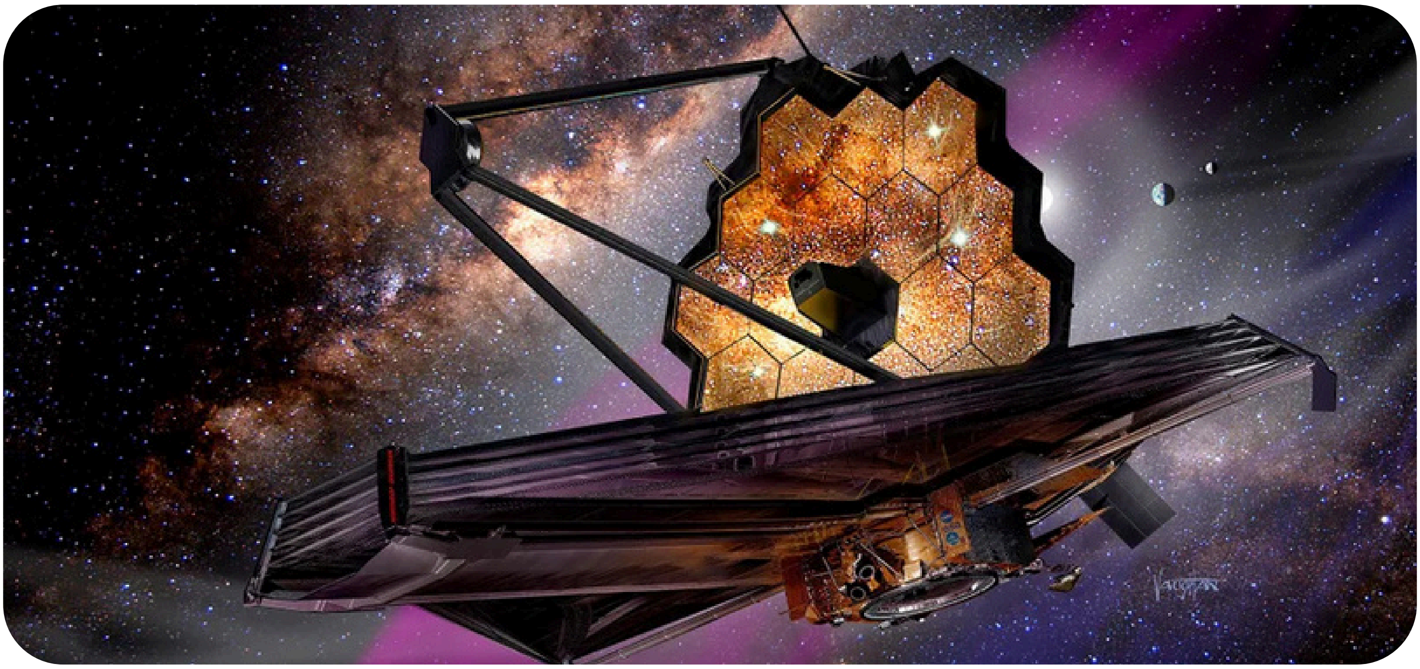
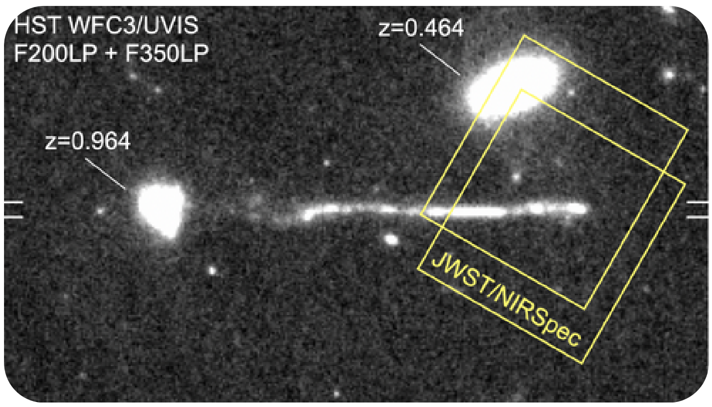
JWST's Most Recent Discoveries: Black Holes, Monster Stars, and the First Light



Since its launch in December 2021, the James Webb Space Telescope (JWST) has been reshaping our understanding of the universe. With its unprecedented infrared sensitivity and high-resolution imaging, in recent months, JWST has made a series of groundbreaking discoveries that allows astronomers to peer deeper into cosmic history than ever before by capturing light from the first stars, galaxies, and black holes that formed after the Big Bang.

JWST CONFIRMS THE FIRST KNOWN 'RUNAWAY' SUPERMASSIVE BLACK HOLE

Astronomers have made a remarkable discovery using the JWST: the first confirmed runaway supermassive black hole. With a mass roughly 10 million times that of the Sun, this black hole is tearing through its home galaxy at about 2.2 million miles per hour (1,000 kilometers per second), making it one of the fastest-moving objects ever observed. This extreme speed has dramatic consequences. As the black hole plows through interstellar gas, it generates a massive, galaxy-scale bow shock in front of it, compressing and heating the surrounding material. It leaves behind an enormous tail of gas stretching roughly 200,000 light-years, within which new stars are actively forming. *[The "wake" of a black hole is the trail of disturbed gas and dust it leaves behind, similar to a boat's wake in water.]*



Hubble image of the runaway supermassive black hole, with its wake later analyzed by JWST.

Supermassive black holes are normally anchored at the centers of galaxies, dominating their surroundings through gravity. The fact that this one has traveled roughly 230,000 light-years from its original position makes it an extraordinary outlier.

The runaway supermassive black hole was first spotted in 2023 by Pieter van Dokkum with the Hubble Space Telescope as a faint, narrow streak of light; the wake of a massive object moving through space. Black holes emit no light themselves, so this one is visible only through the shockwave with which it drives through surrounding gas and the disturbed material in its trail. JWST observations confirmed the interaction, showing gas at the front of the wake being pushed sideways at hundreds of kilometers per second, revealing the black hole's extreme speed, fast enough to escape its host galaxy entirely. Now how does a superfast moving black hole escape it's galaxy?

"It boggles the mind! The forces that are needed to dislodge such a massive black hole from its home are enormous. And yet, it was predicted that such escapes should occur!"

~ Pieter van Dokkum, Yale University

Turns out, there are two ways: a gravitational-wave recoil following a black hole merger, or a chaotic three-body interaction in a binary system. Evidence favors the first scenario in this case. As the black hole travels, its enormous shock wave compresses gas in its wake, triggering star formation far from any galaxy. So far, the wake has produced stars totaling roughly 100 million solar masses, a previously unobserved mode of star formation. Galaxy mergers are common, suggesting that runaway supermassive black holes may not be rare.

HAVE WE FINALLY SEEN THE FIRST STARS IN THE UNIVERSE?

For as long as humans have studied the cosmos, one question has lingered at the edge of astronomy: what were the very first stars like? Formed shortly after the Big Bang, these stars marked the moment the universe first began to glow. These earliest stars, known as Population III stars, are unlike anything we see today. Born from nearly pristine clouds of hydrogen and helium, some theories suggest that dark matter may have played a role in their formation, allowing these stars to grow to truly staggering sizes which is potentially millions of times the mass of the Sun and shining billions of times brighter.

This massive galaxy cluster, MACS J0416, bends light to reveal stars formed shortly after the Big Bang

"If indeed then stars of LAP1-B are Pop III, this is the first detection of these primordial stars. To discover POP III stars, we really needed the sensitivity of JWST, and we also needed the 100 times magnification from gravitational lensing from a galaxy cluster between us and LAP1-B."

~ Eli Visbal, University of Toledo

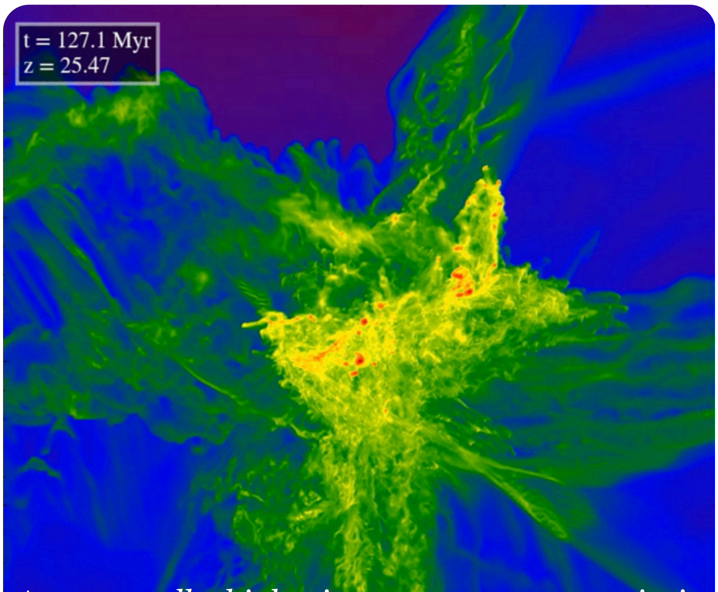
Detecting the first stars directly is extraordinarily difficult, as they formed more than 13 billion years ago and individual stars from that era are far too faint to resolve. Webb's infrared instruments, designed to capture the stretched light of the expanding universe, have revealed distant galaxies dominated by hydrogen and helium, with little evidence of heavier elements. One object, the compact system LAP1-B, closely matches predictions for regions shaped by Population III stars. While Webb has not photographed individual first stars, it has detected the collective glow and chemical fingerprint of a stellar population that appears remarkably primitive. Using gravitational lensing, where massive clusters of galaxies bend spacetime, magnifying and distorting the light from objects behind them. This natural magnification boosts Webb's view by dozens or even hundreds of times. JWST's observations represent the strongest evidence yet for Population III stars, but confirmation will require further observations. Still, we are witnessing a historic moment: for the first time, humanity can study the era when the universe first lit up.

ASTRONOMERS SPOT GIANT 'MONSTER STARS' ILLUMINATING THE UNIVERSE'S EARLIEST ERA

Astronomers have long struggled to explain how supermassive black holes appeared so soon after the Big Bang. Conventional stars evolve too slowly to account for their rapid formation. JWST observations instead point to short-lived "monster stars".

The evidence comes from JWST's observations of a distant galaxy known as GS 3073. When researchers analyzed its light, they found a striking chemical imbalance: nitrogen was present in quantities far exceeding what any known type of stellar explosion can produce. This unusual ratio acts like a forensic clue, pointing to a very specific and exotic origin.

The only explanation that fits is the existence of primordial stars thousands of times more massive than the Sun. Inside these stellar behemoths, helium burning creates carbon, which then fuels an intense chain of reactions that rapidly generates nitrogen, which is mixed throughout the star and released into their host galaxy, permanently altering its chemistry. Rather than exploding as supernovae, many of these short-lived stars likely collapsed directly into black holes. The actively growing black hole in GS 3073 may be the remnant of one such stellar giant.



An unusually high nitrogen-to-oxygen ratio in galaxy GS 3073.

> *"Chemical abundances act like a cosmic fingerprint, and the pattern in GS 3073 is unlike anything ordinary stars can produce. Its extreme nitrogen matches only one kind of source we know of: primordial stars thousands of times more massive than our Sun. This tells us the first generation of stars included truly supermassive objects that helped shape the early galaxies and may have seeded today's supermassive black holes."*
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> *~ Devesh Nandal, Cfa' s Institution for Theory and Computation*