Imagine if paleontologists stumbled on a secluded forest where giant dinosaurs still stomp about. Ten years ago, astronomers were lucky enough to spot the cosmic equivalent: a little galaxy near our own that mimics those that arose at the dawn of time—galaxies so distant that no one has yet seen them.

The dwarf galaxy is named Leo P. “The more I study it, the more attached to it I get,” says Kristen McQuinn of Rutgers University in Piscataway, NJ, with a laugh. “It definitely is my favorite galaxy.” That’s in part because she knows Leo P’s small size and primitive composition match the predicted characteristics of the first galaxies that ever existed. But the galaxy’s proximity to us makes it much easier to observe, promising cosmic insights out of all proportion to its tiny size.

Furthermore, Leo P sports a hot, young star that the Hubble Space Telescope recently scrutinized, a star that likely resembles some of the ones that shone during the early years of the universe. Future observations with the newly launched James Webb Space Telescope should probe the infancy of Leo P itself, giving us a glimpse of how this galaxy took shape shortly after the creation of the cosmos.

**Primordial Primer**

The Big Bang that gave birth to the universe 13.8 billion years ago produced huge amounts of hydrogen and helium, but almost no heavier elements. Approximately 600 to 800 million years later, the hottest stars, perhaps aided by the growing and
glowing centers of galaxies, succeeded in changing the cosmos. By emitting extreme ultraviolet light, these stars ripped electrons from neutral hydrogen atoms in the gas between them and thereby returned the universe to the ionized state of its earliest years. Reionization meant that space became transparent to extreme ultraviolet light, a metamorphosis whose timing and drivers cosmologists would like to understand. Most of space has been ionized ever since.

Because the first galaxies existed so long ago, they appear more than 13 billion light-years distant, beyond even the sight of Hubble. Nevertheless, astronomers suspect that those galaxies were nothing like the giants that light the modern universe. Instead, the early galaxies were dwarfs, many of which would go on to merge with one another to make the giants. Primeval galaxies abounded with the gas that gives birth to new stars, but they largely lacked “metals”—the term astronomers use for all elements heavier than hydrogen and helium. Metals such as oxygen arise from nuclear fusion in stars, which disperse their harvest during their lives and deaths. Right after their birth, however, the first stars had only just begun to enrich the universe with these metals.

In short, cosmologists think that the first galaxies were small, star-forming, gas-rich, and metal-poor—four traits that were turning up surprisingly close to home in the constellation Leo.

**Goldilocks Galaxy**

Radio astronomers first spotted Leo P in 2012. Most galaxies reveal themselves through their starlight, but little Leo P has few stars. The galaxy came to the astronomers’ attention only when the now-defunct Arecibo telescope detected the galaxy’s hydrogen gas, which was giving off 21-centimeter-long radio waves (1).

When light or radio waves travel a vast distance, the expansion of space stretches them to longer or redder wavelengths, producing a redshift effect. But Leo P’s radio waves had only a small redshift, which meant the galaxy was nearby.

Astronomers then examined optical images of that part of the constellation Leo. “Lo and behold, there it was,” McQuinn says. The team saw Leo P’s stars for the first time, sprinkled across 3,700 light-years of space. Best of all, the galaxy boasted a hot, young, massive star that was emitting extreme ultraviolet light and ionizing all hydrogen atoms within 15 light-years of itself (2).

Ionizing radiation causes oxygen, by far the most common metal in the universe, to glow. This light told the astronomers how much oxygen existed in the galaxy relative to hydrogen, the most common element in the cosmos. They found the oxygen level to be a mere 3% that of the Sun, nearly the lowest ever seen in a star-forming galaxy (3), which prompted the astronomers to christen their find Leo P, the “P” meaning “pristine.”

McQuinn and her colleagues then used the galaxy’s stars to calculate that Leo P is just 5.3 million light-years from Earth (4, 5). That distance is thousands of times closer than the very early galaxies, making Leo P a lot easier for astronomers to see. Yet it’s located just beyond the Local Group, the gathering of more than a hundred galaxies that includes the giant Milky Way and Andromeda galaxies.

**“We can use Leo P as a time capsule and try to recover what its early mass assembly was and connect it to what we think was happening in the early universe.”**

—Kristen McQuinn

This separation from the Local Group has helped sustain Leo P’s star-making career. “What sets Leo P apart is its location,” McQuinn says. “Leo P is sort of in this Goldilocks zone.” Most Local Group galaxies are dwarfs that orbit the Milky Way or Andromeda, which have stripped nearly all their satellites of gas. As a result, most Local Group dwarfs can no longer give birth to new stars and so do not resemble the earliest galaxies.

In contrast, Leo P belongs to a loose association made solely of dwarfs; its nearest known neighbor is more than a million light-years away. This isolation has allowed the galaxy to hold on to its gas, which still ekes out new stars, but so slowly that the oxygen level remains low. Indeed, the galaxy’s mass of stars is only 560,000 times that of the Sun, puny even by dwarf standards. Plus, when a star does explode, most of the oxygen it spews escapes the galaxy’s weak gravity. McQuinn estimates that Leo P has lost 95% of the oxygen it has ever made, further helping to keep the galaxy in a primitive, low-metal state (6).

**Rapid Rotators with Weak Winds**

Ultraviolet light from Leo P’s hot, massive star recently yielded another discovery, one that hints at the nature of the first stars that shone: It spins fast. “I actually was surprised,” says Grace Telford at Rutgers, who conducted the observations with McQuinn and colleagues. The star spins at hundreds of kilometers per second, faster than most hot stars in our galaxy. It’s also faster than most hot stars in the Large and Small Magellanic Clouds, two nearby galaxies with oxygen levels less extreme than Leo P’s. In these galaxies, hot stars usually rotate at less than 120 kilometers per second.

Furthermore, Telford found the same story when she looked at a second hot, metal-poor star, this one in a larger dwarf galaxy that belongs to the same association as Leo P. The galaxy, named Sextans A, has an oxygen level that is 6% of the Sun’s, or twice that of Leo P, and its star also spins at hundreds of kilometers per second (7).

The observations stretched the capabilities of the Hubble Space Telescope. “What is surprising is that this team could pull this off,” says Volker Bromm of the University of Texas at Austin, who was not involved in the work. Previous work of this nature had targeted the Magellanic Clouds, but Leo P and Sextans A are more than 20 times farther away than those galaxies. The new findings, he adds, are intriguing and tantalizing for what they imply about the universe’s first stars, stars that no one has yet seen.
One implication is that the metal-poor stars in the early universe spun faster than later generations of higher-metallicity stars, but Telford cautions that “it’s a very small sample size, and so we can’t overstate any claims.” She hopes to firm up this result by studying additional hot stars in Sextans A. Unfortunately, Leo P is so tiny that it has no other equally hot stars to observe.

Telford’s team also found that both of the metal-poor stars have weak winds, or outflows of material. These weak winds help to explain the stars’ rapid rotation. When a star has lots of metals in its atmosphere, they can absorb stellar radiation and get pushed outward. By casting their material away, the stars spin more slowly, like spinning ice skaters who stretch out their arms. In contrast, stars with the fewest metals should have the weakest winds and fastest spins, just as seen in Leo P and Sextans A.

If the first metal-poor stars did indeed spin fast, Bromm says, they would have emitted more ionizing radiation over their lives, in part because a rapid spin can prolong stellar life by mixing fresh hydrogen fuel into the star’s core. That in turn would have sped up the reionization of the early universe, implying that this great cosmic transformation required the work of fewer stars.

These findings likely have other consequences for our understanding of the evolution of early stars, says Avi Loeb of Harvard University in Cambridge, MA. In particular, some of the fast-spinning stars would have turned into fast-spinning black holes when they died. Material spiraling around a fast-spinning black hole shines much more brightly, so Loeb says the new work implies that the outskirts of the first stellar-mass black holes emitted copious amounts of X-rays. These X-rays would have traveled large distances and heated the gas between the galaxies of the early universe.

But Loeb says Leo P is not sufficiently metal-free to see what the first stars were really like. He wants similar observations of a star-forming dwarf galaxy 30 times more metal-poor than Leo P. Theory predicts that the gas in such galaxies spawns a different range of stars. This is because extremely metal-poor gas stays warm, and a warm cloud of gas has significant thermal pressure that hampers the collapse of the cloud to form a star. Therefore, in the universe’s most metal-poor days, only massive gas clouds may have had enough gravity to overcome the thermal pressure and collapse, resulting in heavier stars.

But to study such a primitive galaxy, someone has to discover it. “The dream is always to find a primordial galaxy nearby,” says Trinh Thuan of the University of Virginia in Charlottesville, who has searched for metal-free galaxies for four decades. “But we haven’t found anything.” Five years ago, Thuan and his colleagues did spot a new record breaker: a star-forming galaxy with an oxygen level around 2% that of the Sun (8), although that’s still much higher than Loeb would like. Furthermore, the galaxy is more than a hundred times farther away than Leo P and thus much harder to observe. Nevertheless, Loeb points out that the Milky Way’s halo harbors stars that are extremely metal-poor, suggesting that entire galaxies of such near-primitive stars could exist nearby and still be making new stars. The problem with the halo is that it is old and so has no short-lived massive stars that would resemble the universe’s youngsters.

Meanwhile, McQuinn has already been awarded time on the James Webb Space Telescope, which launched in...
December and moved into position in January, to observe Leo P and deduce how the secluded galaxy came together long ago. "We can use Leo P as a time capsule and try to recover what its early mass assembly was and connect it to what we think was happening in the early universe," she says.

Hubble has already demonstrated that Leo P formed some of its stars more than 10 billion years ago. The new telescope, which is larger, will focus on infrared light, where Leo P's older and cooler stars radiate much of their energy. Through these observations, McQuinn hopes to trace the life story of her favorite galaxy.

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