



Star wars: what killed the universe's massive galaxies?

Astronomers are closer than ever to working out how the biggest galaxies in the cosmos grew so quickly before dying.

26 November 2024 - By JONATHAN O'CALLAGHAN

The formation of galaxies in the universe should follow a fairly simple path. It starts with small galaxies, which then grow bigger and bigger until they become the giant galaxies we see in the modern universe, like our Milky Way. Easy, right?

But that is not strictly true for a particular class of elliptical galaxies – huge spherical collections of stars without a clear structure. With the help of EU funding, researchers have set out to discover the origin of these galaxies and unlock more mysteries of the universe.

To do that, they have travelled back in time, using powerful telescopes that can follow light to remote corners of the universe. This has allowed scientists to look at galaxies as they appeared in the past, even billions of years ago.

“Galaxies are the flag posts of the universe. They are the origins of everything,” said Sune Toft, a cosmologist at the Niels Bohr Institute in Denmark. “Understanding the detailed formation scenarios is the only way to understand the beginning of the universe and where we come from.”

Toft led the EU-funded ConTEst project from 2015 to 2021. The goal was to observe some of the oldest elliptical galaxies possible, stretching back into the first 2 billion years of the 13.8-billion-year history of the universe.

Time travel to remote dark corners: no answers yet

Although researchers have gained some insight into elliptical galaxies, they remain a mystery.

“These have been known for many years, but it’s kind of a conundrum how they form because they are uniformly old and dead in the local universe,” Toft said.

The thinking behind his research was this: as we look further back in time, by observing galaxies that are billions of light years away, at some point we should start to see the progenitors of these galaxies and be able to explain how they were able to grow so massive.

“But the further away we looked, they kept looking old and dead. They have virtually no star formation,” said Toft, referring to the process at the core of galaxies’ evolution.

That meant the galaxies must have grown very quickly in the early universe. Still, it remains unknown exactly how and when.

And there is another riddle: if the galaxies grew quickly, why did they stop growing? And what did that mean for our understanding of hierarchical galaxy structure in the universe, which comprises stars, planetary systems, star clusters and galaxies?

“The small galaxies are supposed to form first. So why are these massive galaxies the first ones to form?” Toft said.

Star formation

His hypothesis was that these galaxies might have undergone intense star formation early on in their history, becoming what are known as starburst galaxies.

Starburst galaxies have extremely dense amounts of dust and gas and can form stars thousands of times the mass of our Sun every year. Our Milky Way, by comparison, forms one new solar mass per year on average.

Using a telescope in Chile called the Atacama Large Millimeter Array, as well as the Hubble Space Telescope and Spitzer Space Telescope, both of which orbited the Earth at the time, Toft set to work.

He found that, in the first one to two billion years after the Big Bang, “there were enough of these star-forming galaxies to turn into the dead galaxies”. These galaxies were dense and compact and looked similar to the cores of elliptical galaxies we see today.

Toft worked on the premise that these progenitor elliptical galaxies formed quickly in the universe before something shut off their star formation.

Then, over the next 10 billion or so years, they gradually accumulated more stars by gobbling up smaller galaxies, adding their stars to the galaxy’s outer regions. Thus, the elliptical galaxies remained old and dead, but could still grow to immense sizes.

The early growth of the ellipticals was likely caused by galaxy mergers that ignited star formation.

“You have two major galaxies going head-on into each other, and the gas gets compressed into the centre of this collision,” said Toft. “This is what you need to have very high star formation rates.”

But what was still not clear was how these galaxies switched off. How did they stop forming stars so quickly and eventually become the dead galaxies we see today?

Quenching

Sirio Belli, an astronomer at the University of Bologna in Italy, is investigating this problem with his Red Cardinal project, an EU-funded initiative running from 2023 to 2028.

It is using the powerful James Webb Space Telescope (JWST), which orbits the Sun, to probe these early galaxies like never before. The emerging idea is that black holes found at the centres of these galaxies are responsible for their evolution.

Almost all galaxies today, including our own, contain a [supermassive black hole](#) at their centre, a huge object millions to billions of times the mass of our Sun. These black holes drive the formation and evolution of a

galaxy, churning and expelling gas and dust throughout a galaxy's history.

Belli has found that these black holes might also be responsible for stopping star formation in early galaxies, in a process referred to as quenching.

In April 2024, his team used JWST to report the discovery of a massive galaxy undergoing quenching about 2.6 billion years after the Big Bang. "It's a lucky coincidence because we observed this galaxy exactly when quenching was happening," he said.

The galaxy appeared to have been growing until recently. "It just stopped forming stars," said Belli.

"At the same time, we found this giant wind coming out of the galaxy. We think this is due to the supermassive black hole at the centre of the galaxy."

The idea is that the black hole became extremely active, which "pushed the gas away from the galaxy", said Belli. "So you don't have any gas to form new stars. It's like a car that runs out of fuel."

What is unclear is exactly why the black hole became active. One possibility is that once the black hole eats enough material and gains enough mass, it suddenly starts releasing a lot of energy, causing quenching.

"We think that once a galaxy reaches a certain mass, 100 billion solar masses, they are then eventually all quenched," said Belli. "We don't see any massive galaxy in today's universe that is still forming stars."

An extremely large telescope to probe further

More answers might come from new telescopes like the European Extremely Large Telescope (ELT), which is being built in Chile and due to begin its observations in 2028.

"With the ELT, we can look in detail inside these galaxies" in the early universe, said Belli, something JWST is not able to do.

That will tell researchers the overall star formation rate, but also "where the stars are being formed", he said. "If the ELT works as promised, it should be pretty cool."

Determining the mechanism of the quenching process will be crucial in unravelling the enigma of why galaxies die, an issue that continues to perplex scientists.

"It shouldn't be possible because when a galaxy is in the early universe, it's filled with gas," said Toft.

"How do you go from forming thousands of solar masses per year to nothing? If we want to prove black holes are responsible, we have to find galaxies right in the process of shutting down."

With that understanding, we will learn how the cosmos as we see it today came to be.

Research in this article was funded by the European Research Council (ERC). The views of the interviewees don't necessarily reflect those of the European Commission. If you liked this article, please consider sharing it on social media.

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