

A young but completely evolved entirely self-made galaxy

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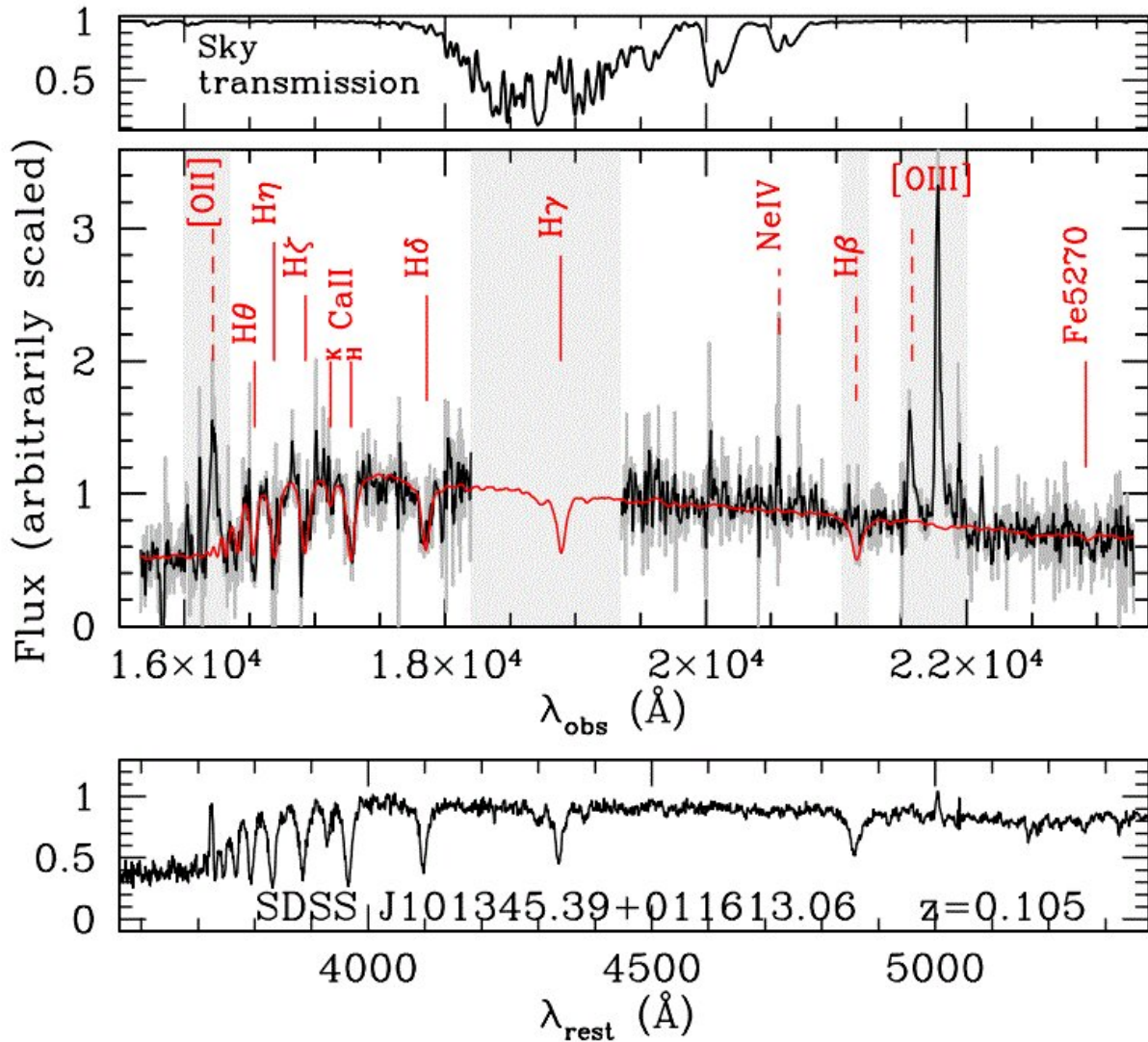
Color image of the galaxy C1-23152 at redshift $z=3.352$, when the universe was 1.8 billion years old. The image is the sum of three images at different wavelengths taken with the Hubble Space Telescope. C1-23152 appears a regular spheroidal galaxy, its light profile matches those of typical elliptical galaxies in the local universe. Its stellar mass is about 200 billion stars like the sun and it formed in less than 500 million years. Credit: Istituto Nazionale di

So young and already so evolved: Thanks to observations obtained at the Large Binocular Telescope, an international team of researchers coordinated by Paolo Saracco of the Istituto Nazionale di Astrofisica (INAF, Italy) was able to reconstruct the wild evolutionary history of an extremely massive galaxy that existed 12 billion years ago, when the universe was only 1.8 billion years old, less than 13% of its present age. This galaxy, dubbed C1-23152, formed in only 500 million years, an incredibly short time to give rise to a mass of about 200 billion suns. To do so, it produced as many as 450 stars per year, more than one per day, a star formation rate almost 300 times higher than the current rate in the Milky Way. The information obtained from this study will be fundamental for galaxy formation models for objects it for which it is currently difficult to account.

The most [massive galaxies](#) in the universe reach masses several hundred billion times that of the sun, and although they are numerically just one-third of all galaxies, they contain more than 70% of the [stars](#) in the universe. For this reason, the speed at which these galaxies formed and the dynamics involved are among the most debated questions of modern astrophysics. The current model of galaxy formation—the so-called hierarchical model—predicts that smaller galaxies formed earlier, while more massive systems formed later, through subsequent mergers of the pre-existing smaller galaxies.

On the other hand, some of the properties of the most massive galaxies observed in the local universe, such as the age of their stellar populations, suggest instead that they formed at early epochs. Unfortunately, the variety of evolutionary phenomena that galaxies can undergo during their lives does not allow astronomers to define the way

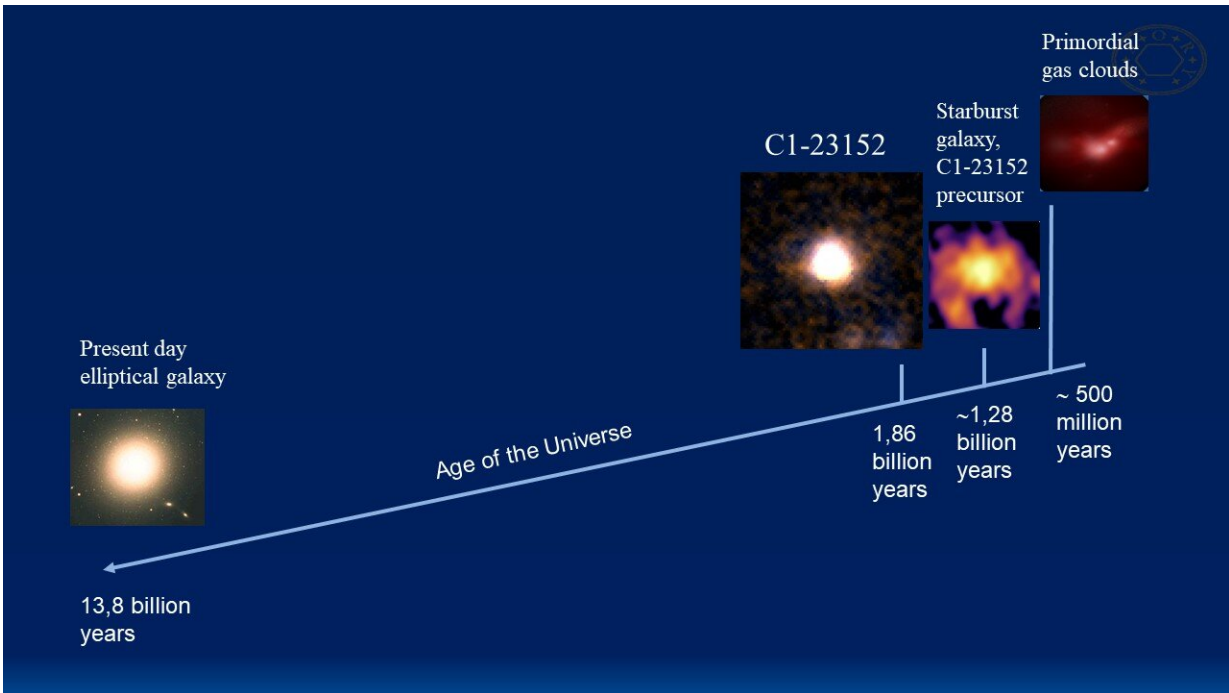
in which they formed, leaving large margins of uncertainty. However, an answer to these questions can come from the study of the properties of massive galaxies in the early universe, as close as possible to the time when they formed most of their mass.



Spectrum of galaxy C1-23152. Credit: Istituto Nazionale di Astrofisica

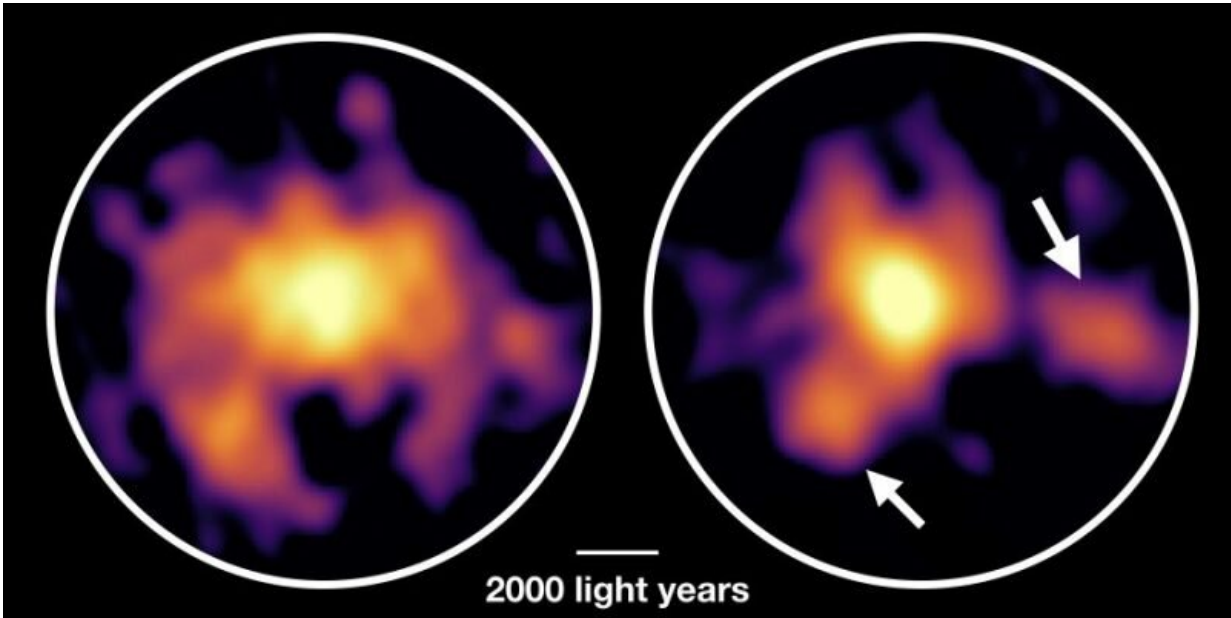
Seventeen hours of spectroscopic observations of the elliptical galaxy C1-23152 with the Large Binocular Telescope (LBT) allowed Saracco's team to reconstruct its evolutionary history at a period when the universe was less than 13% of its current age. "The data show that the formation time of C1-23152, that is, the time elapsed between the formation of the first stars from the pre-existing gas to the moment when the star formation had almost completely ceased, is less than 500 million of years," says Paolo Saracco, researcher at INAF in Milan and first author of the article published in *The Astrophysical Journal*. "Also, from the data collected with LBT, we were able to establish that in this short time, corresponding to less than four-hundredths of the age of the universe, the galaxy formed a mass equal to about 200 billion stars like the sun, that is, about 450 suns per year. Our galaxy, the Milky Way, now forms no more than two a year," adds Danilo Marchesini, full professor at Tufts University and second author of the article. Additionally, the large amount of information collected allowed the team to quantify the abundance of chemical elements heavier than helium (the so-called metallicity) for the first time in a galaxy so distant: The stars of this galaxy have, surprisingly, a higher metallicity than that of the sun, similar to that observed in the most massive galaxies in the universe today.

"These observations showed that the formation of the most massive galaxies in the universe can occur extremely quickly, through an extremely intense star-formation process in the early universe, as for C1-23152," says Francesco La Barbera, researcher at INAF in Naples.



Likely formation scenario of massive elliptical galaxies like C1-23152. Massive primordial gas clouds, falling in the same region under the effect of gravitational force, collide triggering violent and massive star formation processes. The starburst phase is expected to last few hundreds of million years during which hundreds to thousands stars per year are formed, as for C1-23152. The resulting massive elliptical galaxy will then evolve with time, possibly experiencing different evolutionary phenomena. Credit: Istituto Nazionale di Astrofisica

"Understanding whether the scenario that describes the formation of C1-23152 is a particular case or whether, on the contrary, it is what happens for most of the most massive galaxies in the [universe](#), is of fundamental importance, since this would require a profound revision of the galaxy formation models," adds Adriana Gargiulo, also a researcher at INAF in Milan and co-author of the study.



This image shows an example of starburst galaxies forming about a thousand of stars per year at the time of observation. This phase is most likely the formation phase of massive galaxies in the early universe, like C1-23152. Credit: Istituto Nazionale di Astrofisica

The formation of stellar masses as high as for C1-23152 requires both high masses of gas to convert into stars and particular physical conditions. A possible scenario hypothesized by the researchers is that massive primordial gas clouds, falling under the effect of gravitational force in the same region, collide, triggering violent and massive star formation processes. From the observational point of view, the precursors of the most massive galaxies could therefore be remote [galaxies](#) with a very high rate of star formation.

"To test our hypotheses, the observations that the next generation of instrumentations will allow us to carry out will be decisive, in particular, the James Webb Space Telescope (JWST) which will be launched into orbit at the end of 2021, and the Extremely Large Telescope (ELT) the

largest ground-based telescope ever built, with a main mirror of 39 meters in diameter, which will be operational in 2026," concludes Saracco.

More information: Paolo Saracco et al. The Rapid Buildup of Massive Early-type Galaxies: Supersolar Metallicity, High Velocity Dispersion, and Young Age for an Early-type Galaxy at $z = 3.35$, *The Astrophysical Journal* (2020). [DOI: 10.3847/1538-4357/abc7c4](https://doi.org/10.3847/1538-4357/abc7c4)

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