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The JWST is rewriting astronomy textbooks

June 6 2024, by Evan Gough

The first JWST Deep Field Image, showing large distant galaxies. The telescope's observations are revealing the previously unseen and are forcing a re-write of astronomy textbooks. Credit: NASA, ESA, CSA, STScI

When the James Webb Space Telescope was launched at the end of 2021, we expected stunning images and illuminating scientific results. So far, the powerful space telescope has lived up to our expectations. The JWST has shown us things about the early universe we never anticipated.

Some of those results are forcing a rewrite of astronomy textbooks.

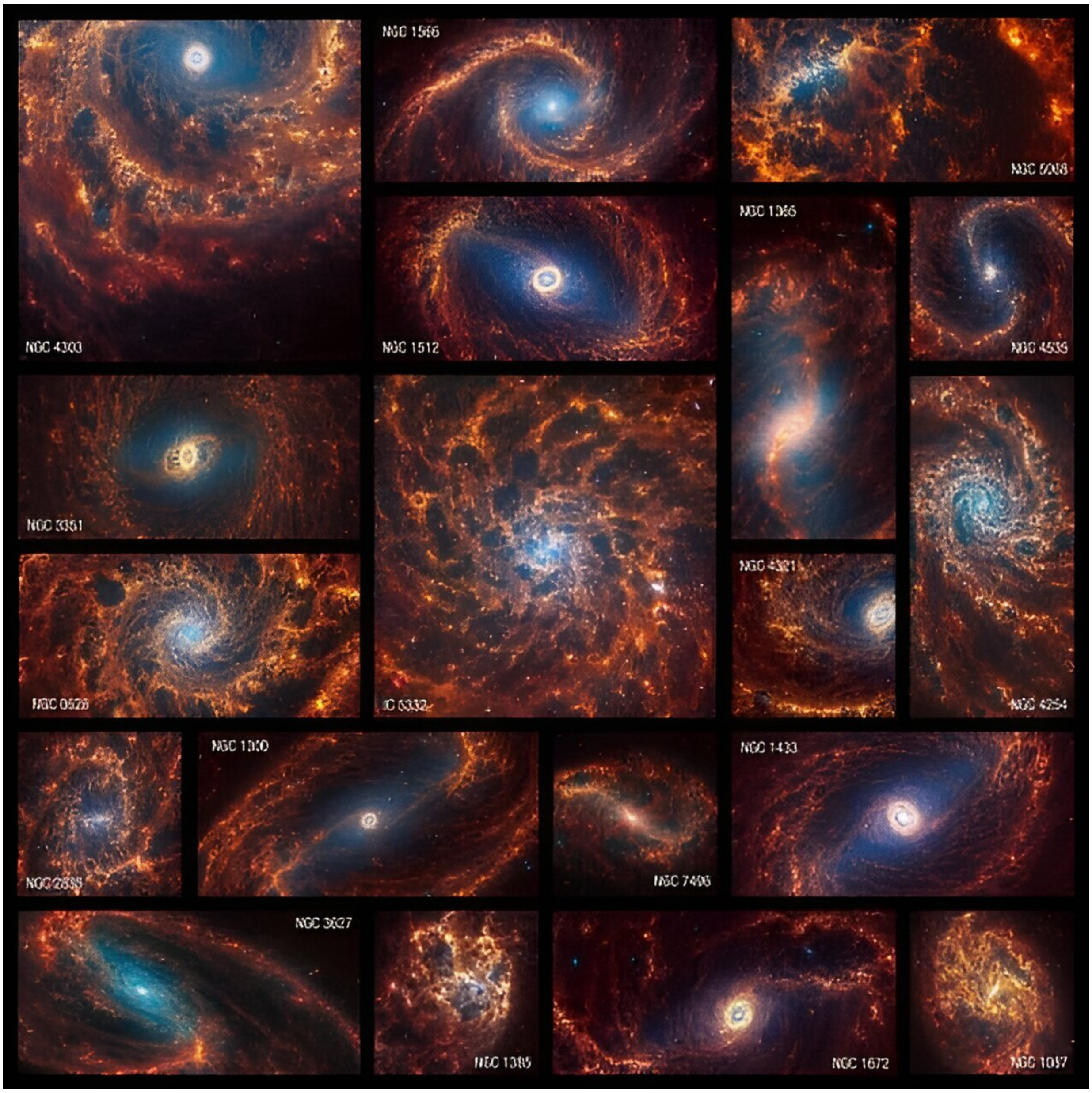
Textbooks are regularly updated as new evidence works its way through the scientific process. But seldom does new evidence arrive at the speed the JWST is delivering it. Chapters on the early universe are in need of a significant update.

At the recent 2024 International Space Science Institute (ISSI) Breakthrough Workshop in Bern, Switzerland, a group of scientists summed up some of the telescope's results so far. Their work is detailed in a new paper posted to the *arXiv* preprint server titled "The First Billion Years, According to JWST."

The list of authors is long, and those authors are quick to point out that an even larger group of international scientists played a role. It takes an international scientific community to use JWST observations and advance the "collective understanding of the evolution of the early universe," as the authors write.

The early universe is one of the JWST's primary scientific targets. Its infrared capabilities allow it to see the light from ancient galaxies with greater acuity than any other telescope. The telescope was designed to directly address confounding questions about the high-redshift universe.

The following three broad questions are foundational issues in cosmology that the JWST is addressing.

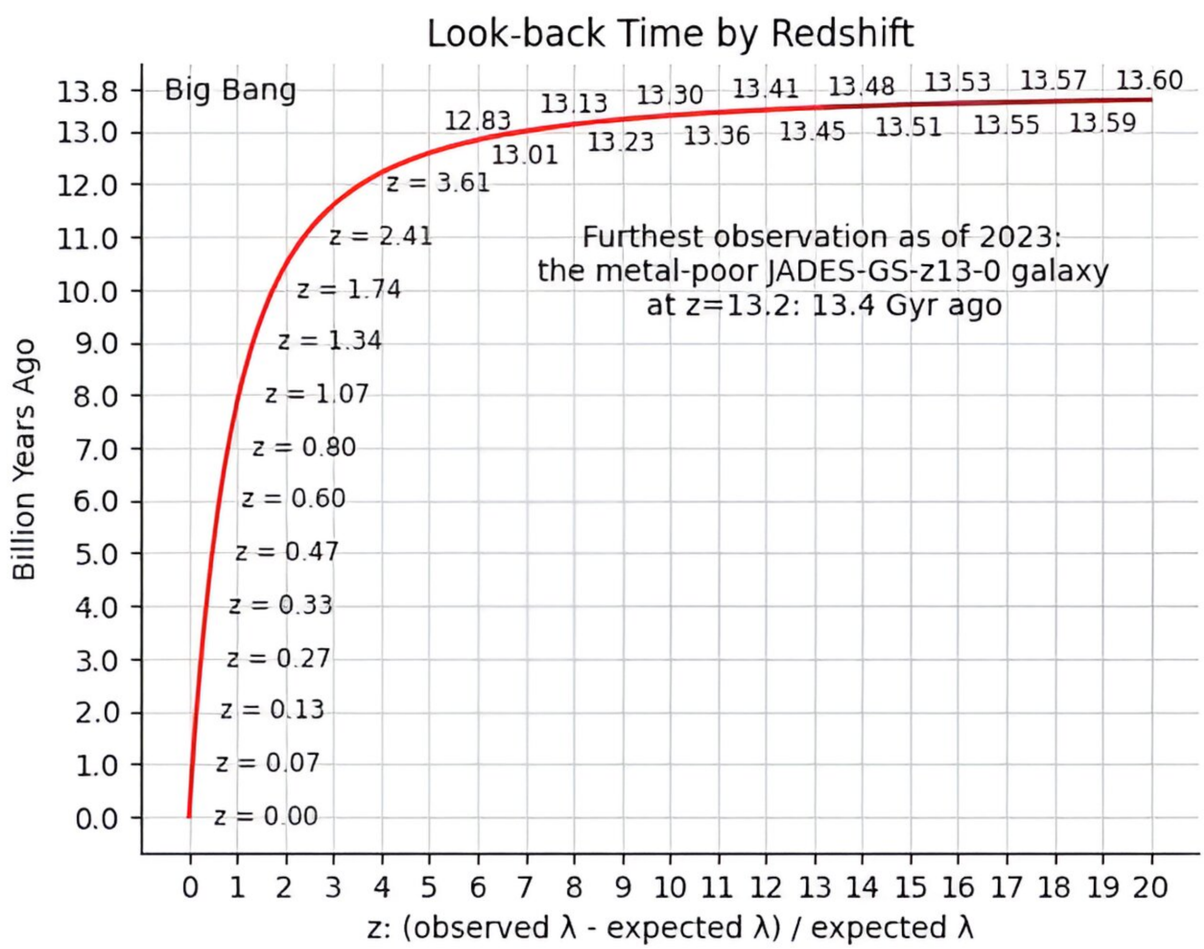


The JWST captured these images of 19 face-on spiral galaxies as part of the Physics at High Angular resolution in Nearby GalaxieS (PHANGS) program. The telescope has shown us that early galaxies were much larger than expected. Credit: NASA, ESA, CSA, STScI, J. Lee (STScI), T. Williams (Oxford), PHANGS Team, E. Wheatley (STScI)

What are the physical properties of the earliest galaxies?

The early universe and its transformations are fundamental to our understanding of the universe around us today. Galaxies were in their infancy, stars were forming, and black holes were forming and becoming more massive.

The Hubble Space Telescope was limited to observations at about z=11. The JWST has shoved that boundary aside. Its current high-redshift observations have reached z=14.32. Astronomers think that the JWST will eventually observe galaxies at z=20.



The lookback time of extragalactic observations by their redshift up to z=20.
Credit: Sandizer – Own work, CC0,
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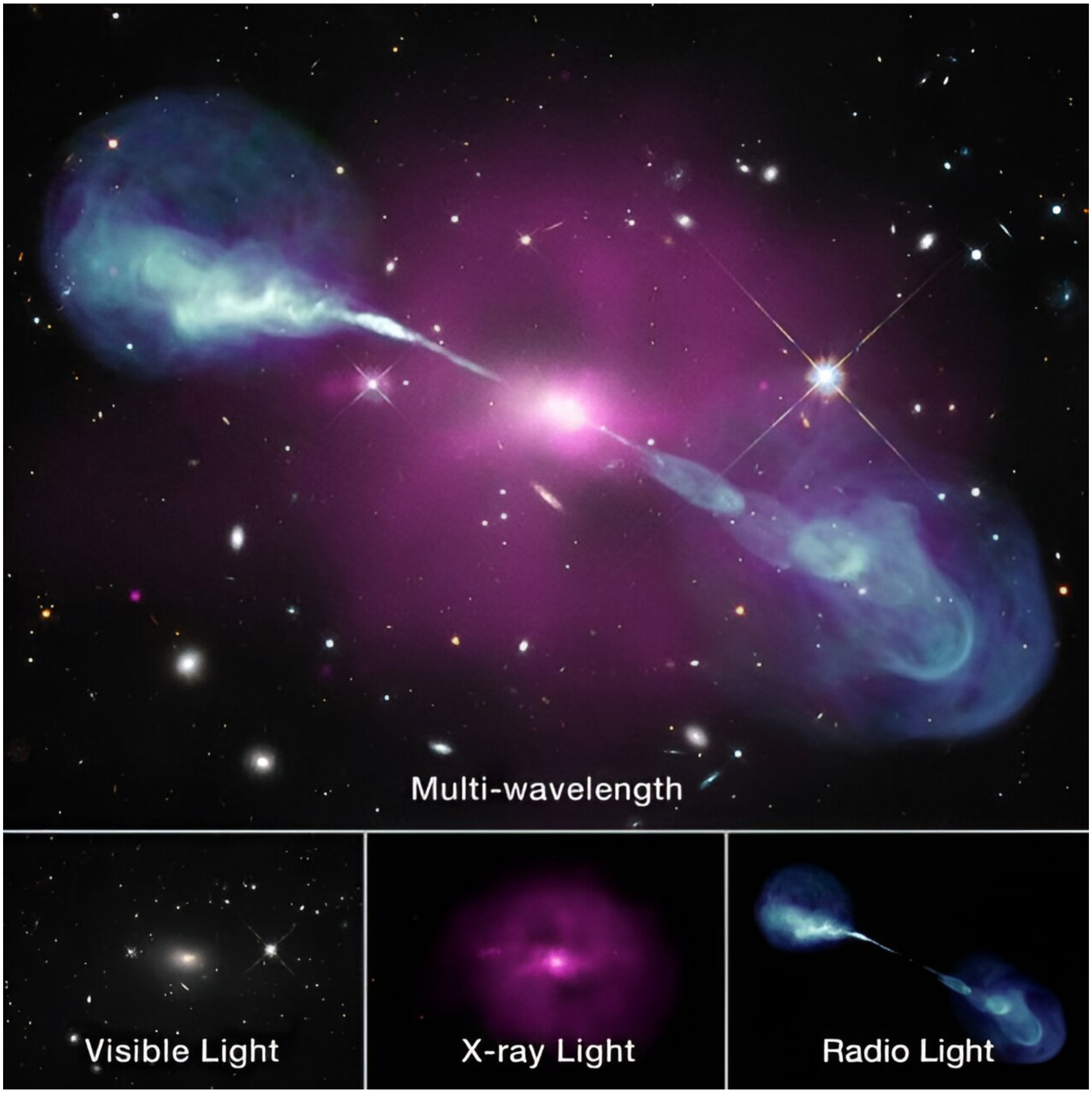
The first few hundred million years after the Big Bang is called the Cosmic Dawn. JWST showed us that ancient galaxies during the Cosmic Dawn were much more luminous and, therefore, larger than we expected. The galaxy the telescope found at z=14.32, called JADES-GS-z14-0, has several hundred million solar masses.

"This raises the question: How can nature make such a bright, massive, and large galaxy in less than 300 million years?" scientists involved with JWST Advanced Deep Extragalactic Survey (JADES) said in a NASA post.

It also showed us that they were differently shaped, that they contained more dust than expected, and that oxygen was present. The presence of oxygen indicates that generations of stars had already lived and died. "The presence of oxygen so early in the life of this galaxy is a surprise and suggests that multiple generations of very massive stars had already lived their lives before we observed the galaxy," the researchers wrote in the post.

"All of these observations, together, tell us that JADES-GS-z14-0 is not like the types of galaxies that have been predicted by theoretical models and computer simulations to exist in the very early universe," they continued.



This image shows Hercules A, a galaxy in the Hercules constellation. The X-ray observations show superheated gas, and the radio observations show jets of particles streaming away from the AGN at the center of the galaxy. The jets are almost 1 million light-years long. Credit: X-ray: NASA/CXC/SAO; visual: NASA/STScI; radio: NSF/NRAO/VLA.

What is the nature of active galactic nuclei in early galaxies?

Active galactic nuclei (AGN) are supermassive black holes (SMBHs) that are actively accreting material and emitting jets and winds.

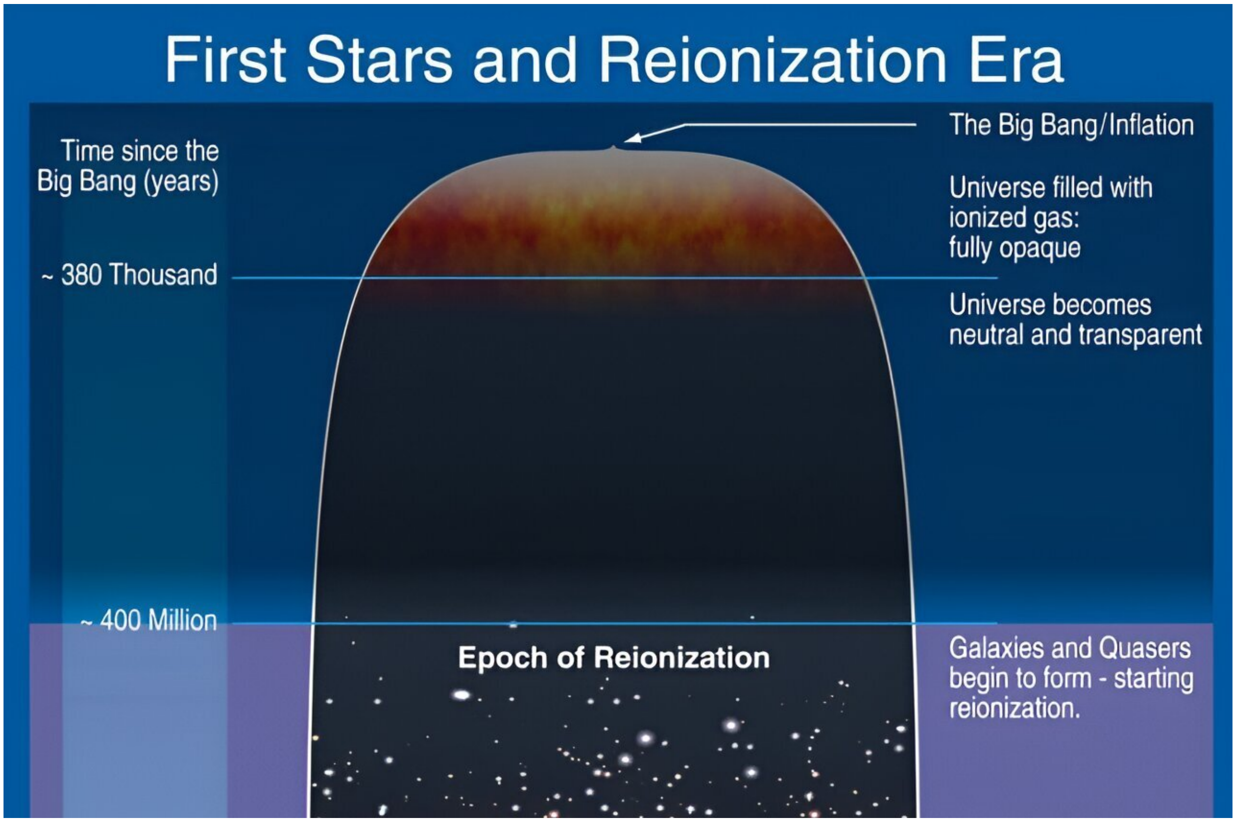
Quasars are a sub-type of AGN that are extremely luminous and distant, and quasar observations show that SMBHs were present in the centers of galaxies as early as 700 million years after the Big Bang. But their origins were a mystery.

Astrophysicists think that these early SMBHs were created from black hole "seeds" that were either "light" or "heavy." Light seeds had about 10 to 100 solar masses and were stellar remnants. Heavy seeds had 10 to 10^5 solar masses and came from the direct collapse of gas clouds.

The JWST's ability to effectively look back in time has allowed it to spot an ancient black hole at about z=10.3 that contains between 10^7 to 10^8 solar masses. The Hubble Space Telescope didn't allow astronomers to measure the stellar mass of entire galaxies the way that the JWST does.

Thanks to the JWST's power, astronomers know that the black hole at z=10.3 has about the same mass as the stellar mass of its entire galaxy. This is in stark contrast to modern galaxies, where the mass of the black hole is only about 0.1% of the entire stellar mass.

Such a massive black hole existing only about 500 million years after the Big Bang is proof that early black holes originated from heavy seeds. This is actually in line with theoretical predictions. So, the textbook authors are now in a position to remove the uncertainty.



This graphical timeline of the Universe shows where the Epoch of Reionization fits in. Credit: NASA – NASA, Public Domain, https://commons.wikimedia.org/w/index.php?curid=6272041

When and how did the early universe become ionized?

We know that in the early universe, hydrogen became ionized during the Epoch of Reionization (EoR). Light from the first stars, accreting black holes, and galaxies heated and reionized the hydrogen gas in the intergalactic medium (IGM), removing the dense, hot, primordial fog that suffused the early universe.

Young stars were the primary light source for the reionization. They created expanding bubbles of ionized hydrogen that overlapped one another. Eventually, the bubbles expanded until the entire universe was ionized.

This was a critical phase in the development of the universe. It allowed future galaxies, especially dwarf galaxies, to cool their gas and form stars. But scientists aren't certain how black holes, stars, and galaxies contributed to the reionization or the exact time frame in which it took place.

"We know that hydrogen reionization happened, but exactly when and how it happened has been a major missing piece in our understanding of the first billion years," the authors of the new paper write.

Astronomers knew that reionization ended about 1 billion years after the Big Bang, at about redshift z=5-6. But before the JWST, it was difficult to measure the properties of the UV light that caused it. With the JWST's advanced spectroscopic capabilities, astronomers have narrowed down the parameters of reionization.

"We have found spectroscopically confirmed galaxies up to z = 13.2, implying reionization may have started just a few hundred million years after the Big Bang," the authors write.

JWST results also show that accreting black holes and their AGN likely contributed no more than 25% of the UV light that caused reionization.

These results will require some rewriting of textbook chapters on the EOR, even though there are still lingering questions about it. "There is still significant debate about the primary sources of reionization, in particular, the contribution of faint galaxies," the authors write. Even though the JWST is extraordinarily powerful, some distant, faint objects are beyond its reach.

The JWST is not even halfway through its mission and has already transformed our understanding of the universe's first one billion years. It was built to address questions around the Epoch of Reionization, the first black holes, and the first galaxies and stars. There's definitely much more to come. Who knows what the sum total of its contributions will be?

As an astronomy writer, I'm extremely grateful to all of the people who brought the JWST to fruition. It took a long time to build, cost a lot more than expected, and was almost cancelled by Congress. Its perilous path to completion makes me even more grateful to be covering its results. The researchers using JWST data are clearly grateful, too.

"We dedicate this paper to the 20,000 people who spent decades to make JWST an incredible discovery machine," they write.

More information: Angela Adamo et al, The First Billion Years, According to JWST, *arXiv* (2024). DOI: 10.48550/arxiv.2405.21054

Provided by Universe Today

Citation: The JWST is rewriting astronomy textbooks (2024, June 6) retrieved 20 June 2024 from https://phys.org/news/2024-06-jwst-rewriting-astronomy-textbooks.html