Tracing 13 billion years of history by the light of ancient quasars

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Artist's rendering of the accretion disk in ULAS J1120+0641, a very distant quasar powered by a supermassive black hole with a mass two billion times that of the Sun. Credit: ESO/M. Kornmesser

Astrophysicists in Australia have shed new light on the state of the universe 13 billion years ago by measuring the density of carbon in the gases surrounding ancient galaxies.

The study, published in *Monthly Notices of the Royal Astronomical Society*, adds another piece to the puzzle of the history of the universe.

"We found that the fraction of carbon in warm gas increased rapidly about 13 billion years ago, which may be linked to large-scale heating of gas associated with the phenomenon known as the Epoch of Reionization," says Dr. Rebecca Davies, ASTRO 3D Postdoctoral Research Associate at Swinburne University of Technology, Australia and lead author of the paper describing the discovery.

The study shows the amount of warm carbon suddenly increased by a factor of five over a period of only 300 million years—the blink of an eye in astronomical timescales.

While previous studies have suggested a rise in warm carbon, much larger samples—the basis of the new study—were needed to provide statistics to accurately measure the rate of this growth.

"That's what we've done here. And so, we present two potential interpretations of this rapid evolution," says Dr. Davies.

The first is that there is an initial increase in carbon around galaxies simply because there is more carbon in the universe.

"During the period when the first stars and galaxies are forming, a lot of heavy elements are forming because we never had carbon before we had stars," Dr. Davies says. "And so one possible reason for this rapid rise is just that we're seeing the products of the first generations of stars."

However, the study also found evidence that the amount of cool carbon decreased over the same period. This suggests that there might be two different phases in the evolution of the carbon—a rapid rise while reionization occurs, followed by a flattening out.

The Epoch of Reionization, which took place when the universe was "only" one billion years old, was when the lights came back on after the cosmic Dark Ages following the Big Bang.

Before this the universe was a dark, dense fog of gas. But as the first massive stars formed, their light began to shine through space and reionize the cosmos. This light may have led to rapid heating of the surrounding gas, causing the rise in warm carbon observed in this study.

Studies of reionization are vital to understand when and how the first stars formed and began producing the elements that exist today. But measurements have been notoriously difficult.

"The research led by Dr. Davies was built on an exceptional sample of data obtained during 250 hours of observations on the Very Large Telescope (VLT) at the European Southern Observatory in Chile," says Dr. Valentina D'Odorico from the Italian Institute for Astrophysics, the Principal Investigator of the observational program. "This is the largest amount of observing time assigned to a single project carried out with the X-shooter spectrograph.

"Thanks to the 8m VLT we could observe some of the most distant quasars, which act as flashlights, illuminating galaxies along the path from the early universe to the Earth."

Rebecca Davies,. Credit: ASTRO 3D

As the quasar light passes through galaxies in its 13-billion-year journey across the universe, some photons are absorbed, creating distinctive barcode-like patterns in the light, which can be analyzed to determine the chemical composition and temperature of gas in the galaxies.

This gives an historical picture of the development of the universe.

"These 'barcodes' are captured by detectors at the VLT's X-Shooter spectrograph," Dr. Davies explains. "This instrument splits the galaxy light into different wavelengths, like putting light through a prism, allowing us to read the barcodes and measure the properties of each galaxy."

The study led by Dr. Davies captured more barcodes of ancient galaxies than ever before.

"We increased from 12 to 42 the number of quasars for which we had high quality data, finally allowing a detailed and accurate measurement of the evolution of the carbon density," says Dr. D'Odorico.

This major advance was enabled by the ESO VLT, one of the most advanced telescopes on Earth, and a strategic partner of Australia.

"The study provides a legacy data set which will not be significantly improved until 30m-class telescopes comes online towards the end of this decade," says Professor Emma Ryan-Weber, a Chief Investigator in the ARC Centre of Excellence for All Sky Astrophysics in 3 Dimensions (ASTRO 3D) and second author of the study. "High quality data from even earlier in the universe will require access to telescopes like the Extremely Large Telescope (ELT) now under construction in Chile."

Astronomers are using many different types of data to build a history of the universe.

"Our results are consistent with recent studies showing that the amount of neutral hydrogen in intergalactic space decreases rapidly around the same time," says Dr. Davies.

"This research also paves the way for future investigations with the Square Kilometre Array (SKA), which aims to directly detect emission from neutral hydrogen during this key phase of the universe's history."

Professor Ryan-Weber says the research goes to the heart of ASTRO 3D's mission to understand the evolution of elements, from the Big Bang to present day: "It addresses this key goal: How did the building blocks of life—in this case carbon—proliferate across the universe?

"As humans we strive to understand 'Where did we come from?' It's incredible to think that the barcode of those 13-billion-year-old carbon atoms were imprinted on photons at a time when [...] Earth didn't even exist. Those photons traveled across the universe, into the VLT, and then were used to develop a picture of the evolution of the universe."

More information: Rebecca Davies et al, Examining the Decline in the C~IV Content of the Universe over 4.3 = z = 6.3 using the E-XQR-30 Sample, *Monthly Notices of the Royal Astronomical Society* (2023). DOI: 10.1093/mnras/stad294

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