Shedding light on the formation of massive galaxies

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A new array of submillimeter and millimeter wavelength antennas has begun operating in the Atacama Desert of northern Chile, allowing astronomers to study the formation of the first galaxies.

In the young universe, some of the most massive galaxies were extremely rich in the molecular gas used to fuel star formation. Observations of this gas are essential for understanding how galaxies both obtain their gas and turn it into stars. The ionized atomic gas and dust in these galaxies can emit strongly at far-IR (FIR) wavelengths. For the most distant galaxies, this emission is redshifted to submillimeter and millimeter wavelengths. High FIR luminosity in a galaxy can be attributed to ongoing starburst activity, where the interstellar dust is heated by young stars and emits thermal radiation at longer wavelengths. Furthermore, line emission from molecules such as carbon monoxide and hydrogen cyanide can be observed at radio wavelengths in order to study the molecular gas that drives star formation activity. However, for studies of the most distant galaxies, the brightest line in the FIR spectrum is typically the 157.7\,\mu m line of ionized carbon ([CII]). This line arises throughout much of the interstellar medium and is now commonly detected in distant galaxies.

New telescopes operating at submillimeter to centimeter wavelengths are capable of studying the atomic and molecular gas, along with thermal emission from cold dust, in galaxies from the first few hundred million years after the Big Bang. The Atacama Large Millimeter/submillimeter Array (ALMA) is the largest of these telescopes ever constructed. It is able to observe [CII] line emission with high spatial resolution and provide limits on the gas kinematics in galaxies that existed during the first half of the age of the universe. It is being built at 5000m elevation in northern Chile by the European Southern Observatory (representing its member states), the US National Science Foundation, the Japanese National Institutes of Natural Sciences, the Canadian National Research Council, the Taiwanese National Science Council, and the Academia Sinica Institute of Astronomy and Astrophysics. In parallel with the commissioning and science verification phase of ALMA, early science observations with sixteen 12m-diameter antennas began in 2011. The first results have demonstrated the extreme sensitivity of ALMA for the study of gas and dust in distant galaxies.

As part of the commissioning, observations at 340GHz of redshifted dust continuum and [CII] line emission were made toward a pair of massive galaxies known as BR1202-0725 (see Figure 1), existing 1.3 billion years after the Big Bang. Two luminous galaxies are detected, one of which was originally discovered as an optically luminous quasar hosting a massive black hole. The second bright submillimeter source is heavily obscured at optical wavelengths and is believed to be a gas-rich starburst

Figure 1. This image from the Atacama Large Millimeter/submillimeter Array shows thermal dust continuum emission, redshifted to 340GHz, in the quasar host galaxy, BR1202-0725. This system contains at least two, and possibly three, massive interacting galaxies that existed 1.3 billion years after the Big Bang.
The ALMA data also reveals a third fainter companion to the two massive galaxies. We believe that all three are part of the same group, possibly in the process of interacting. Since it is likely that this system will evolve into an elliptical galaxy with primarily old stars—similar to what is seen in the nearby universe—these observations can provide insight into how the first massive galaxies formed.

We detect [CII] line emission in the two luminous members of the BR1202-0725 system, and the spectra represent some of the most sensitive observations of this line in the young universe. The data shows evidence for an outflow of ionized gas from the quasar that can potentially terminate star formation in the interstellar medium of these massive galaxies. Such an outflow has been observed in another luminous quasar host galaxy that existed 850 million years after the Big Bang. \(^5\)

Future ALMA observations of ionized atomic gas in distant galaxies should reveal the processes by which these objects acquired their gas and limit the chemical evolutionary state of their interstellar media. Even with less than one-third of the final number of antennas in this array, astronomers are obtaining images of the thermal emission from cold dust in distant galaxies. These observations are an order of magnitude more sensitive than what was previously obtained with other telescopes. This new facility will provide sensitive, sub-arcsecond spatial resolution maps of the dust and gas in the most distant galaxies, and ultimately transform our understanding of galaxy formation.

The author is grateful to all of his collaborators who contributed to the analysis of the ALMA data and to the staff of the European Southern Observatory, the National Astronomical Observatory of Japan, the National Radio Astronomy Observatory, and the Joint ALMA Observatory, and many others from around the world who have worked very hard to make this new facility a reality. This work was co-funded under the Marie Curie Actions of the European Commission (FP7-COFUND).

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### References