Capturing the onset of galaxy rotation in the early universe

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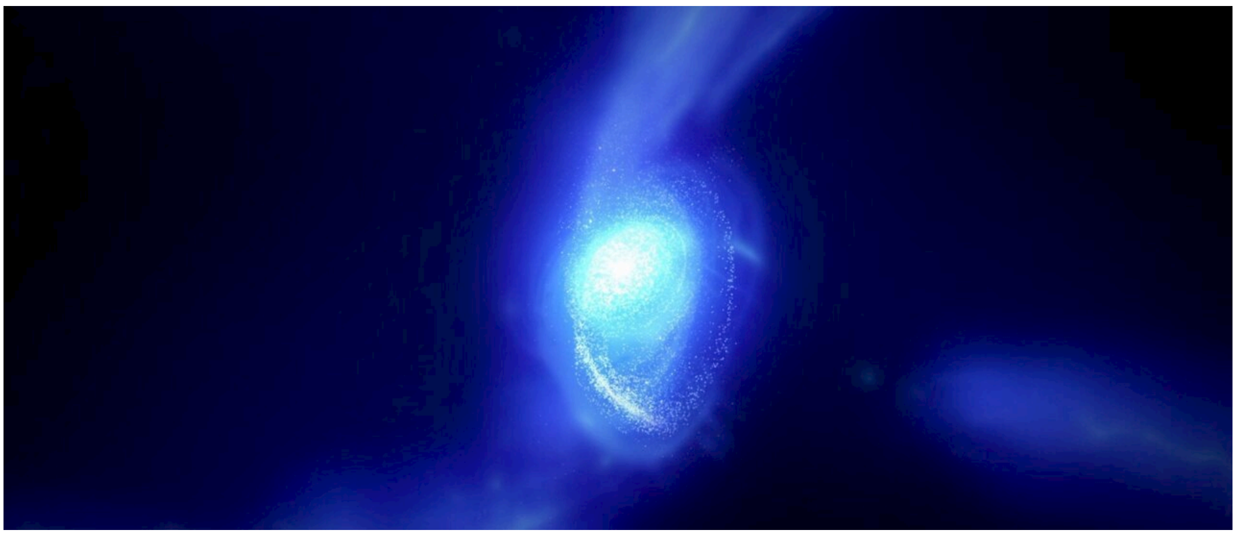
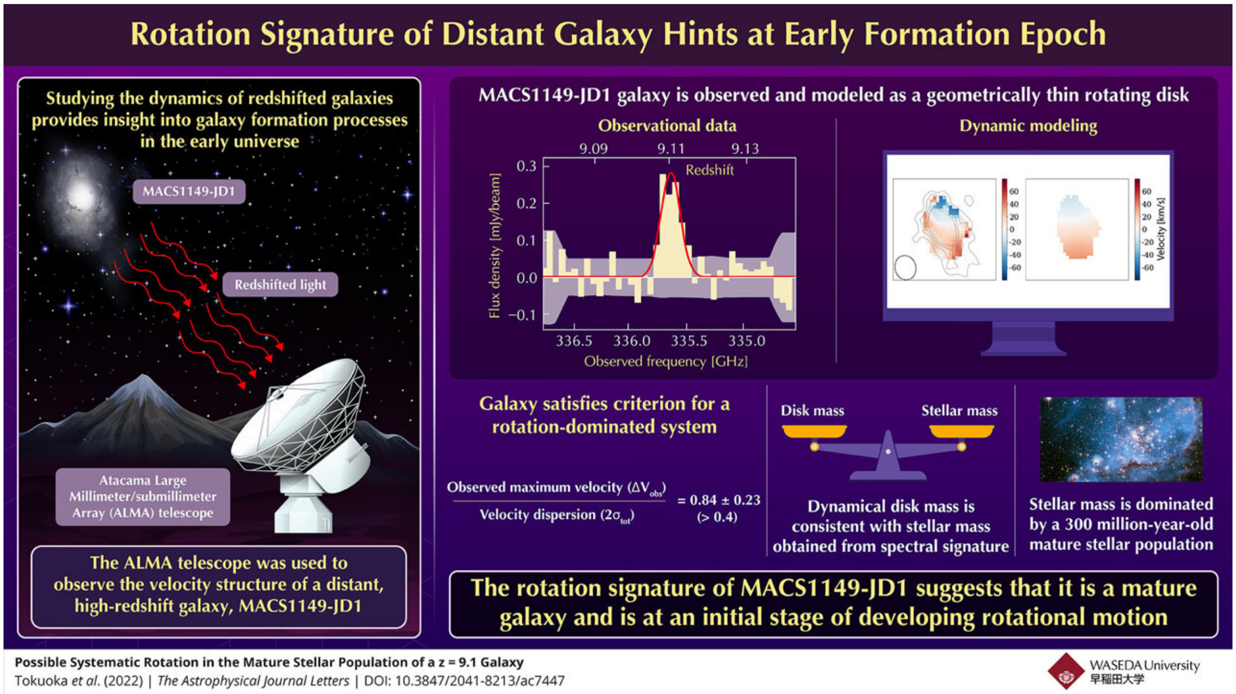


Conceptual image of MACS1149-JD1 forming and spinning up to speed in the early Universe. Credit: ALMA (ESO/NAOJ/NRAO)

As telescopes have become more advanced and powerful, astronomers have been able to detect more and more distant galaxies. These are some of the earliest galaxies to form in our universe that began to recede away from us as the universe expanded. In fact, the greater the distance, the faster a galaxy appears to move away from us. Interestingly, we can estimate how fast a galaxy is moving, and in turn, when it was formed based on how "redshifted" its emission appears. This is similar to a phenomenon called the Doppler effect, where objects moving away from an observer emit the light that appears shifted towards longer wavelengths (hence the term "redshift") to the observer.

The Atacama Large Millimeter/submillimeter Array (ALMA) telescope, located in the midst of the Atacama Desert in Chile, is particularly well-suited for observing such redshifts in galaxy emissions. Recently, a team of international researchers including Professor Akio Inoue and graduate student Tsuyoshi Tokuoka from Waseda University, Japan; Dr. Takuya Hashimoto at University of Tsukuba, Japan; Professor Richard S. Ellis at University College London; and Dr. Nicolas Laporte, a research fellow at the University of Cambridge, UK has observed redshifted emissions of a distant galaxy, MACS1149-JD1 (hereafter JD1), which has led them to some interesting conclusions. "Beyond finding high-redshift, namely very distant galaxies, studying their internal motion of gas and stars provides motivation for understanding the process of galaxy formation in the earliest possible universe," explains Ellis. The findings of their study have been published in *The Astrophysical Journal Letters*.

Galaxy formation begins with the accumulation of gas and proceeds with the formation of stars from that gas. With time, star formation progresses from the center outward, a galactic disk develops, and the galaxy acquires a particular shape. As star formation continues, newer stars form in the rotating disk while older stars remain in the central part. By studying the age of the stellar objects and the motion of the stars and gas in the galaxy, it is possible to determine the stage of evolution the galaxy has reached.



After the Big Bang came the earliest galaxies. Due to the expansion of the universe, these galaxies are receding away from us. This causes their emissions to be redshifted (shifted towards longer wavelengths). By studying these redshifts, it is possible to characterize the "motion" within the galaxies as well as their distance. In a new study, astronomers at Waseda University have now revealed a likely rotational motion of one such distant galaxy. Credit: Waseda University

Conducting a series of observations over a period of two months, the astronomers successfully measured small differences in the "redshift" from position to position inside the galaxy and found that JD1 satisfied the criterion for a galaxy dominated by rotation. Next, they modeled the galaxy as a rotating disk and found that it reproduced the observations very well. The calculated rotational speed was about 50 kilometers per second, which was compared to the rotational speed of the Milky Way disk of 220 kilometers per second. The team also measured the diameter of JD1 at only 3,000 light-years, much smaller than that of the Milky Way at 100,000 light-years across.

The significance of their result is that JD1 is by far the most distant, and therefore, the earliest source yet found that has a rotating disk of gas and stars. Together with similar measurements of nearer systems in the research literature, this has allowed the team to delineate the gradual development of rotating galaxies over more than 95% of our cosmic history.

Furthermore, the mass estimated from the rotational speed of the galaxy was in line with the stellar mass previously estimated from the galaxy's spectral signature, and came predominantly from that of "mature" stars that formed about 300 million years ago. "This shows that the stellar population in JD1 formed at an even earlier epoch of the cosmic age," says Hashimoto.

"The rotation speed of JD1 is much slower than those found in galaxies in later epochs and our galaxy, and it is likely that JD1 is at an initial stage of developing a rotational motion," says Inoue. With the recently launched James Webb Space Telescope, the astronomers now plan to identify the locations of young and older stars in the galaxy to verify and update their scenario of galaxy formation.

New discoveries are surely on the horizon.

More information: Possible Systematic Rotation in the Mature Stellar Population of a z = 9.1 Galaxy, *The Astrophysical Journal Letters* (2022). DOI: 10.3847/2041-8213/ac7447

Provided by Waseda University