ASTRONOMY

Early star formation detected

Little is known about the star-birth activity of the earliest galaxies. Observations of a particularly distant galaxy provide evidence for such activity when the Universe was just 2% of its current age. See Letter p.392

RYCHARD BOUWENS

Astronomers have only a limited understanding of star and galaxy formation in the first 300 million years of the Universe's history[1,2]. Two important processes would have been accretion, whereby objects increase in mass by gravitationally attracting nearby matter, and the cooling of gas. But the overall picture lacks the sensitive observational data required to inform or guide its construction. On page 392, Hashimoto *et al.*[3] present observations of an extremely distant galaxy, and report that star-birth activity began there just 250 million years after the Big Bang. The authors' results suggest that future telescopes could detect such early episodes of star formation in similar galaxies.

The first stars in the Universe are thought to have formed in regions with high densities of matter[1,2]. These regions grew over cosmic time by accretion, and eventually developed into galaxies. From a theoretical standpoint, there is great interest in establishing observationally when the Universe had its first major star-birth activity, but current constraints are poor. One way in which to investigate the onset of star formation is to detect starlight from extremely distant galaxies. Because light travels at a finite speed, observations of the distant Universe act as a time machine, allowing us to look back into the past.

The galaxy probed by Hashimoto and colleagues is one of the farthest known objects from Earth for which light can be detected (Fig. 1a). It was discovered[4] in 2012, and was dubbed MACS1149-JD1. What the authors have added to this discovery is a precise measurement of the galaxy's redshift. The redshift of a light source tells us the factor by which the Universe has expanded since the source emitted its light, as well as the distance to the source and the time at which the light was released.

Hashimoto *et al.* determined the redshift of MACS1149-JD1 by studying the properties of an emission line in the galaxy's spectrum. They report a redshift of about 9.11, which implies that the galaxy is being viewed as it was when the Universe was roughly one-tenth of its current size and about 550 million years old. This is the highest redshift ever inferred from a spectral line[5], and is only slightly lower than a redshift reported by using a broader, possibly less robust, spectral feature[6].

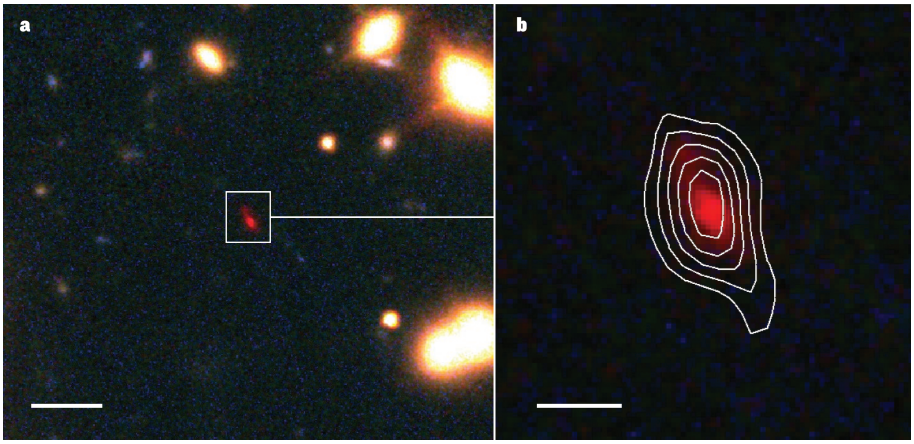

Figure 1 | Observations of MACS1149-JD1. a, Hashimoto *et al.*[3] report that star formation in the distant galaxy MACS1149-JD1 (indicated by the box) began when the Universe was only 2% of its current age. Other sources of light in the image are nearby galaxies. Scale bar, 2 arcseconds (one arcsec is 1/3,600th of a degree). **b**, The authors' result relied on a detailed study of an emission line in the galaxy's spectrum that is produced by doubly ionized oxygen. The contours join points that have equal emission-line intensity. Scale bar, 0.5 arcsec. (Adapted from Extended Data Fig. 2a of ref. 3.)

The authors' measurement was made possible thanks to the continuously improving capabilities of the US$1.4-billion Atacama Large Millimeter/submillimeter Array (ALMA) observatory in Chile. ALMA studies of galaxies with redshifts greater than 4 frequently use an emission line that is produced by singly ionized carbon[7–9]. By contrast, Hashimoto and colleagues relied on a line that is associated with doubly ionized oxygen (Fig. 1b). This line was shown to be readily detectable in previous theoretical and observational work using ALMA[10,11]. The authors' result showcases ALMA's capabilities as a tool for precisely measuring the redshifts of distant galaxies, as was also illustrated earlier this year[7].

Next, Hashimoto *et al.* considered the optical colours observed in MACS1149-JD1 by NASA's Hubble and Spitzer space telescopes. Such colours provide clues about the number of stars that formed early in a galaxy's lifetime[4,12,13]. The authors show that the colours represent a substantial episode of star formation in the galaxy when the Universe was only 250 million years old. The authors' precise redshift measurement was essential in arriving at this conclusion because it allowed them to rule out the possibility that the colours arise instead from strong recombination lines — spectral features that are commonly associated with the intense ionizing radiation produced by hot stars in the earliest galaxies[14–16].

However, MACS1149-JD1 is just one galaxy, and it remains unclear whether such early star-birth activity occurred in other galaxies. Observations of the cosmic microwave background — the relic radiation from the Big Bang — by the Planck Collaboration[17] indicate that there was less star formation in the early Universe than the present authors' results suggest. In addition, measurements of the prevalence of galaxies at similar epochs to that of MACS1149-JD1 suggest a lack of star-birth activity at these early times[18]. Nevertheless, a high rate of star formation in the early Universe could explain the discovery earlier this year of an unexpectedly large absorption signal in the spectrum of the cosmic microwave background[19].

Hashimoto and colleagues have not only set a record for the highest redshift inferred from a spectral line, but they also did it using ALMA, which is a first for the facility. The possibility that the galaxy they observed had substantial star formation at early times is intriguing. Their discoveries seem certain to inspire similar studies of other galaxies in the distant Universe, and provide fuel for observations using the future James Webb Space Telescope. ■

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COMPUTATIONAL NEUROSCIENCE

AI mimics brain codes for navigation

An artificial-intelligence technique called deep learning has now been used to model spatial navigation. The system develops a representation of space similar to that of the grid cells found in the mammalian brain. SEE LETTER P.429

FRANCESCO SAVELLI & JAMES J. KNIERIM

Deep learning is an approach to artificial intelligence that is inspired by the brain's neural networks. The technique is contributing to a plethora of technologies, from automated video analysis to language translation. One page 429, Banino *et al.*[1] use this framework to gain insights into real-life neuronal networks — in particular, how geometrically regular representations of space can facilitate flexible navigation strategies.

Deep-learning networks can be taught how to process inputs to achieve a particular output — for instance, learning to pick out a particular face in many photos of different people. The networks are 'deep' in that they are made up of sequential layers of repeated computational units. Each unit receives inputs from similar units in the previous layer and sends outputs to those in the next. Mathematically, such a network can be viewed as a high-dimensional function, which can be modulated by altering how the outputs of one layer are weighted in the next.

The network tunes the function during a training phase, which typically relies on a set of input–output examples. For instance, a deep-learning system might be shown a series of photos, and told which ones contain the face it aims to identify. Its weights are automatically tuned by optimization algorithms until it learns to make a correct identification. The network's deep organization gives it a prodigious ability to spot and take advantage of the most useful features and patterns that recur across the examples, and distinguish different faces. But one downside is that the final network tends to be a black box — the computational solutions derived during training often cannot be deciphered from the myriad weights assigned throughout the layers.

Deep-learning networks can successfully perform perceptual tasks[2], but there have been fewer studies of complex behavioural tasks such as navigation. A key aspect of real-life navigation is estimating one's position following each step, by calculating the displacement per step on the basis of orientation and distance travelled. This process is called path integration and is thought by neuroscientists, cognitive scientists and roboticists to be crucial for generating a cognitive map of the environment[3–5]. There are several kinds of neuron associated with the brain's cognitive maps, including place cells, which fire when the organism occupies a particular position in the environment, and head-direction cells, which signal head orientation.

A third type of neuron, the grid cell, fires when the animal is at any of a set of points that form a hexagonal grid pattern across the environment. Grid cells are thought to endow the cognitive map with geometric properties that help in planning and following trajectories. These cells are found in the brain's hippocampal formation, a region that, in humans, is involved in spatial learning, autobiographical memories and knowledge of general facts about the world.

Banino and colleagues set out to generate path integration in a deep-learning network. Because path integration involves

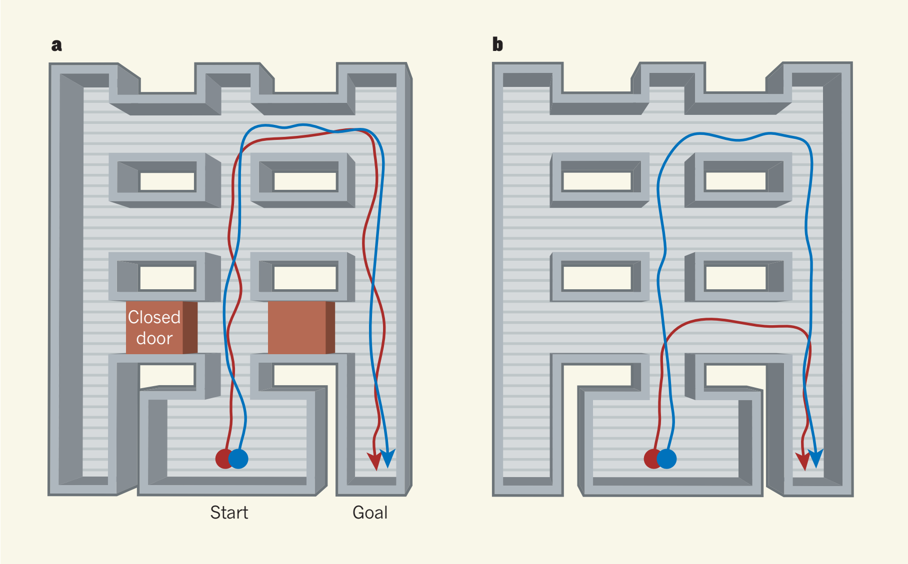

Figure 1 | An AI system learns to take shortcuts. In the mammalian brain, place cells fire when an animal is at a particular position within an environment, head-direction cells fire when the head is in a particular orientation, and grid cells fire when the animal is at points that form a hexagonal grid across the environment. Banino and colleagues[1] trained an artificial-intelligence system called a deep-learning network to navigate, by providing it with simulations of rodent foraging patterns, including about the activity of place and head-direction cells. Some computational units in the network developed grid-cell-like firing patterns (not shown). **a**, While learning to navigate towards a goal, similar paths were taken by both a system using grid cells (red line indicates a sample path) and a system that used place and head-direction cells instead (blue line). **b**, But when shortcuts were introduced, for example by opening previously closed doors, only the system that used grid cells found the shorter routes, highlighting the ability of grid-cell-like activity to promote flexible navigation strategies. (Figure adapted from Extended Data Fig. 10 in ref. 1.)