ASTROPHYSICS

One of the first of the second stars

The chemical content of a star that was born relatively shortly after the formation of the Milky Way calls into question conventional understanding of how stars formed in the early Universe.

JOHN COWAN

How did the first stars form early in the history of our Galaxy and the Universe, and what were these stars like? The Big Bang produced only hydrogen, helium and some lithium, so the first stars would have contained only those elements. Given that the stars became extinct long ago, they were probably quite massive — the more massive a star (with masses more than 80 times that of the Sun a possibility), the shorter its lifetime (as little as a few million years). However, we can learn much about the early conditions in our Galaxy, including the types of element formed and the nature of these first stars, by studying surviving stars from a second generation of stars, which formed from the debris of the first. These surviving 'second stars', which are less massive than the Sun and live for many billions of years, can be found in the Galactic halo. Writing in *Astronomy & Astrophysics*, Caffau *et al.*[1] describe a Galactic halo star that is one of the earliest members of this second generation.

This new work is an extension, and expansion, of Caffau and colleagues' initial report[2] on this star, which is catalogued in the Sloan Digital Sky Survey and known by the non-sexy name of SDSS J102915+172927. The authors used the Very Large Telescope (VLT) in Chile to undertake a detailed spectroscopic analysis[1] of the elements contained in the star, which is in the centre of the constellation Leo. They report that the star has an extremely low abundance of iron — approximately 1/130,000 that of the Sun. Astronomers refer to a star's iron abundance as its metallicity. This metallicity generally correlates with Galactic time: iron is produced in exploding stars, known as supernovae, and its abundance in our Galaxy has increased progressively over time. Thus, the most iron-deficient — or extremely metal-poor (EMP) — stars are among the oldest, having formed relatively soon after the Galaxy itself, early in the history of the Universe.

And yet SDSS J102915+172927 does not have the lowest known iron abundance. Two other stars[3,4] are even more iron-poor, implying that they are older than the star in Leo. Compared to the Sun, however, both stars have a large abundance of carbon and nitrogen relative to iron, as has been noted in several other EMP stars. By contrast, Caffau *et al.*[1] found that carbon and nitrogen were not enhanced in SDSS J102915+172927 — the abundance of these elements with respect to that of iron is consistent with solar values. Similarly to some other EMP stars[4], the abundance of oxygen could not be measured in SDSS J102915+172927. However, Caffau and colleagues also defined a metal-mass fraction based on the total abundance of all of the elements heavier than helium, rather than just that of iron. They report that SDSS J102915+172927 has the lowest such value ever measured, and argue that this makes its composition similar to that of the primordial gas that existed shortly after the Big Bang.

The types and abundances of these elements in old, low-metallicity stars are crucial to our understanding of what happened before the stars' formation. First, it is a puzzle how a low-mass star such as SDSS J102915+172927 (which is less massive than the Sun) even formed early in the history of the Galaxy at a time when high-mass stars would seem to be more common. Observational and theoretical studies[5,6] have suggested that elements such as carbon or oxygen are necessary for cooling (low-mass) parent gas clouds sufficiently for them to eventually collapse and form low-mass stars. The difference between SDSS J102915+172927, which has a relatively low carbon abundance, and carbon-enhanced metal-poor (CEMP) stars calls into question what is normal for these early stars[7]. But with so few stars of this type observed, it is difficult to discern a pattern.

Perhaps SDSS J102915+172927 is older than the other EMP stars observed: the relationship between iron abundance and time might not be entirely linear so early on, and thus the lowest metallicity star might not be the oldest. SDSS J102915+172927 might fall into the transition region between the first generation of stars (sometimes referred to as Population III) and the second generation, or Population II; halo, EMP and CEMP stars belong to the latter group.

Or perhaps SDSS J102915+172927 formed in a region of the Galaxy that had particularly low levels of elements heavier than helium. Although carbon can be produced internally in ageing (giant) stars, this star is probably an (unevolved) main-sequence star — a stellar phase similar to the current state of the Sun — and not a giant or a sub-giant[2]. This means that the carbon and other heavy elements observed in SDSS J102915+172927 must have been synthesized in a supernova and then incorporated into the gas that would form new stars.

The chemical-abundance pattern observed in SDSS J102915+172927 is consistent with what is predicted for such a supernova event[2]. Yet this star in Leo does not have enhanced carbon, in sharp contrast to one of the unevolved carbon-enhanced EMP stars, which also has detectable strontium[4] — a rare heavy element made only in supernovae by a series of neutron captures.

A large scatter in the abundance of heavy, neutron-capture elements with respect to iron is observed for metal-poor stars. (There are many metal-poor halo stars but only a few EMP stars.) This scatter suggests that, at early times, the Galaxy was an unmixed, or non-homogeneous entity, with individual element-synthesis events — that is, supernovae — scattered throughout the halo[8]. Thus, the greatly varying carbon abundances in these early stars might also result from this heterogeneity. Clearly, observations of additional stars will be needed to probe this early phase of the Milky Way.

Further support for this early history of the Galaxy was provided by Caffau and colleagues' measurement[1,2] of the lithium abundance in SDSS J102915+172927. Lithium, produced in the Big Bang, is expected to be at a uniform and primordial abundance level (denoted as the Spite plateau[9]) in these early stars. Surprisingly, however, the measured lithium abundance in this, and another[4], EMP star is low, below the observed Spite plateau. This suggests, at least for some of these early stars, that there is probably a lithium-destruction mechanism occurring during star formation. It will be crucial to find additional evidence of variations in lithium abundance to better understand the earliest stages of star formation.

There will be more stars such as SDSS J102915+172927. Only a small fraction of the thousands of stars in the SDSS database has been observed with the VLT. Nevertheless, this new discovery is a valuable first step in filling in the gaps in our knowledge of the early history of the Universe, and of how stars and elements were formed. ■

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NEUROSCIENCE

Circuits drive cell diversity

Neurons of the same type can show functional differences. It turns out that this diversity is in part the result of the cells' adaptation to their specific neural networks. SEE LETTER P.375

NATHANIEL URBAN & SHREEJOY TRIPATHY

Modern manufacturing was revolutionized by the use of interchangeable parts so similar in their function that any one could effectively replace any other. Making such parts meant that manufacturers did not need to keep track of which nut worked with which bolt or which piston was intended to go in which cylinder. Similarly, most physiological analyses ignore cell-to-cell variation and focus instead on differences between cell types, as though each cell of a specific class were functionally equivalent to any other cell of the same type. However, neuroanatomists have long marvelled at the snowflake-like diversity apparent in the shapes of individual neurons, even within a cell type. And recent analyses have demonstrated that same-class neurons show substantial heterogeneity in their intrinsic properties[1–3], although the origin of such diversity is poorly understood. On page 375 of this issue, Angelo *et al.*[4] report that physiological variability among mitral cells (a type of neuron in the olfactory system) is at least partly caused by differences in the inputs that they receive.

Sensory neurons in the nose are activated when odorant molecules bind to specific receptor proteins on the neurons' surface. This activation is transmitted as an excitatory signal along nerve fibres (axons) that terminate in structures called glomeruli, which cover the surface of the brain's olfactory bulb. Each of about 2,000 glomeruli in the mouse olfactory bulb receives axons from sensory neurons that express a single type of odorant receptor (Fig. 1).

Mitral cells receive these excitatory signals from the sensory neurons and are the main source of the olfactory bulb's output to the cerebral cortex; of note, each mitral cell is connected to a single glomerulus. Although they have long been considered to be a single class of neuron, mitral cells show substantial variation in their physiological properties[1,2]. This is probably because of differences in the expression of certain ion channels — pores in the cell membrane that mediate the transmission of electrical signals by allowing the passage of specific ions. Indeed, Angelo *et al.* have previously observed[1] that mitral cells display considerable diversity in the magnitude of a transmembrane current known as a 'sag'. This current, which is generated when the resting electric potential across the neuron's membrane is intensified, is believed to regulate the sensitivity and timing of mitral cells' responses to periodic sensory inputs (such as those generated when an animal sniffs rapidly).

To explore the causes of variability in sag currents, the authors simultaneously recorded the sag from pairs of mitral cells belonging to either the same or different glomeruli, in slices of mouse olfactory bulb. Although sag magnitude was highly variable from one cell to the next, the variability was markedly lower between mitral cells that received input from the same glomerulus than between cells that received input from different glomeruli.

Why are same-glomerulus mitral cells so homogeneous? The hypothesis explored by Angelo *et al.* is that neurons with similar levels of activity acquire similar physiological features. Pairs of mitral cells connected to the same glomerulus have the same sources of input (Fig. 1) and will therefore have more similar activity levels than random pairs of mitral cells. If the expression of sag-mediating ion channels is affected by a neuron's activity, then this could account for the relative homogeneity of mitral cells connected to the same glomerulus.

To address this issue, the authors cleverly

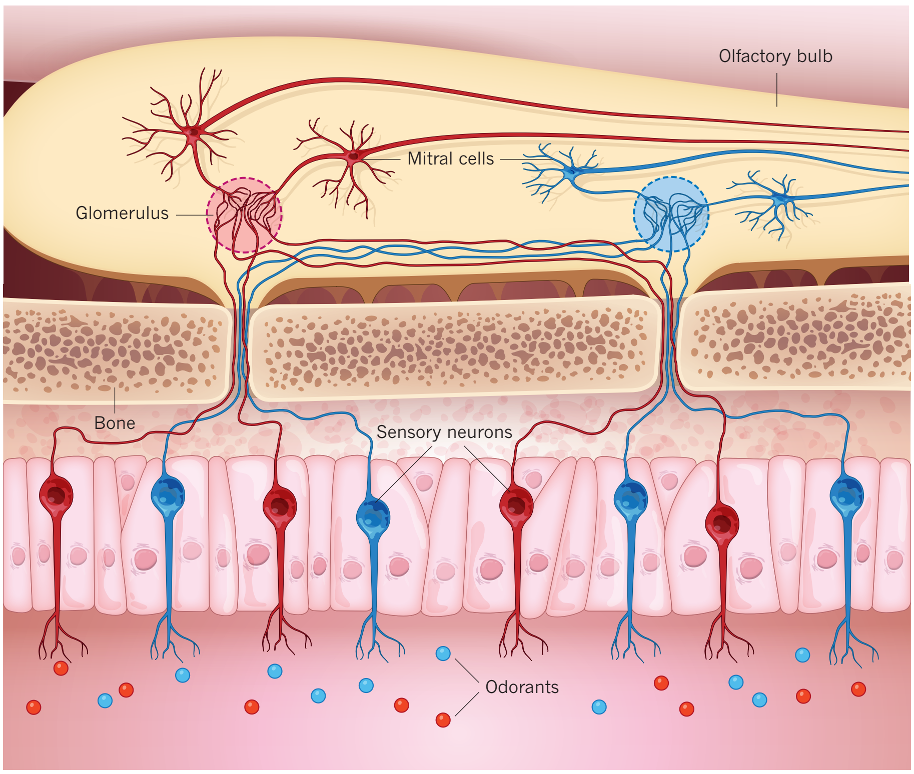

Figure 1 | The importance of network affiliation. Sensory neurons in the nose are activated by specific odorants or groups of odorants (different types are indicated by different colours), and transmit this information to mitral cells, another type of neuron in the brain's olfactory bulb. The transmission takes place in spherical structures called glomeruli, each of which receives input from a single type of sensory cell. Angelo *et al.*[4] report that mitral cells that are linked to the same glomeruli are functionally more similar to each other than to mitral cells that connect to other glomerular networks. This result suggests that input heterogeneity drives functional diversity of mitral cells.