therefore contributes no CO_2 net release to the atmosphere. For the other compounds, however, the emissions are net releases. Finally, as far as checks and balances are concerned, Ludwig *et al.* note that although biomass burning for domestic purposes might well increase as the population increases, that will diminish the stock of fuel for wild fires.

This paper[2] constitutes a new chapter in our understanding of biomass burning as a source of environmentally important atmospheric trace gases. Ironically, atmospheric chemists will be appraising the lessons to be learned from it at the same time as they assess the environmental impact of a more dramatic component of fuel combustion — the burning of Iraqi oil fields. ■

Joel S. Levine is at the NASA Langley Research Center, Hampton, Virginia 23681, USA.
e-mail: j.s.levine@larc.nasa.gov

1. Crutzen, P. J., Heidt, L. E ., Krasnec, J. P., Pollock, W. H. & Seiler, W. *Nature* **282,** 253–256 (1979).
2. Ludwig, J. *et al. J. Atmos. Chem.* **44,** 23–37 (2003).
3. Crutzen, P. J. & Andreae, M. O. *Science* **250,** 1669–1678 (1990).
4. Levine, J. S. (ed.) *Biomass Burning and Global Change*, Vols 1 and 2 (MIT Press, Cambridge, Massachusetts, 1996).

Astronomy

Elements of surprise

John Cowan

The discovery of a very distant galaxy for which the abundances of around 25 elements can be measured promises new insight into the history of element creation and star formation in the Universe.

In the Big Bang at the beginning of the Universe, the lightest elements, hydrogen, helium and lithium, were created. Two other light elements (beryllium and boron) are produced in interstellar space in interactions between cosmic-ray particles and gas atoms[1]. But all of the other elements that exist in nature have been synthesized in nuclear reactions — 'nucleosynthesis' — inside stars, from where they are ejected into interstellar space and eventually find their way into new stars and planets.

Astronomers have made detailed studies of the synthesis of elements in the Milky Way[2] and in some relatively nearby galaxies[3]. But little was known about the production of elements, and the associated history of star formation, in the most distant galaxies that formed early in the history of the Universe. On page 57 of this issue, Prochaska *et al.*[4] report observations of the abundance of elements in a galaxy far away and less than 2.5 billion years old. Their work opens a new window on the early formation of elements and stars in the Universe.

A number of studies have explored 'damped Lyman alpha' (DLA) systems, in which clouds of hydrogen gas are detected through the radiation they absorb from even more distant quasars. These studies probe the earliest chemical history of gas in the Universe, the gas that would form the first stars in the first galaxies. Prochaska *et al.* were able to identify a DLA galaxy along the line of sight to a more distant quasar (known as FJ081240.6+320808). The distance of an object is usually indicated in terms of its 'redshift' — how much the wavelength of its emitted light has increased on its way to Earth, due to the expansion of the Universe. The DLA galaxy has a redshift, z, of 2.626 and the quasar of 2.701. Such large shifts towards the red end of the spectrum indicate that these objects are at great distances: in this case, it took almost 12 billion years for the light from this galaxy to reach Earth.

It is significant that this 'galaxy at redshift $z = 2.626$' (its only designated name so far) is the first distant galaxy to be found that, because of its substantial number of sufficiently abundant elements, is suitable for additional, detailed abundance studies. Prochaska *et al.* followed up their initial discovery with high-resolution studies of the galaxy's radiation spectrum using the HIRES spectrograph of the Keck I telescope in Hawaii. In contrast to many earlier studies that were limited only to intergalactic gas clouds and only a few elements, these authors observed approximately 25 elements in the galaxy at $z = 2.626$, including a number of heavy elements such as zinc and germanium.

The presence of these elements, particularly those heavier than iron, in such a young galaxy is striking. Fundamentally, it seems to indicate that in the galaxies (or at least in this galaxy) that formed relatively shortly after the Big Bang, the onset of star formation and related element production was very rapid. Indeed, Prochaska *et al.* argue in favour of nucleosynthesis in massive stars, which could have formed rapidly and which have very short lifetimes (a few million years), ending in violent supernova explosions. Further supporting that view is the presence of elements such as oxygen, magnesium and sulphur in this galaxy — such elements are characteristically produced in massive stars[5].

Abundance determinations in objects as far away as the galaxy at $z = 2.626$ are complicated by the effects of dust. Some elements might be incorporated in dust particles, depleting their observed abundance in the galactic gas. Nevertheless, based on our knowledge of this problem in our own Galaxy, it is possible to obtain total elemental abundances. Remarkably, the total abundance pattern found by Prochaska *et al.* is consistent with a scaled version of the abundance pattern for the Solar System. Because the galaxy at $z = 2.626$ was formed early in the Universe's history and is so much older than the Solar System (which is only 4.5 billion years old), this consistency of elemental abundances suggests that there are some cosmic universalities or similarities in the synthesis history of all elements.

It should be noted, however, that only upper limits, not absolute values, were measured for the abundances of the chemically interesting heaviest elements, tin and lead, in this distant galaxy. A number of puzzles also remain in interpreting and understanding the abundance distribution. Much germanium, for example, is produced in the Solar System by a process of slow neutron-capture (known as the s-process). This nucleosynthetic process is thought to occur in low-mass stars that take billions of years to live and die[6], and hence it could not be a means of producing germanium as early in the history of the Universe as the observations of the galaxy at $z = 2.626$ would suggest. It may be that germanium production is tied to the overall metal abundance of galactic gas, as seems to be the case in some stars in the Milky Way[7]. Also not yet quantified is the role of the other neutron-capture process (rapid or r-process), which may well be contributing to the abundances of some of these heavier elements. Further abundance studies, particularly for elements such as lead, will be needed to help untangle the history of element formation in this galaxy.

What is most encouraging about Prochaska and colleagues' findings is that there may be other such distant and young galaxies that can be similarly studied and analysed. The authors already report a second distant galaxy, with a different redshift, but surprisingly along the same line of sight as the first galaxy that they observed. They further suggest that around 2% of high-redshift galaxies may be suitable for abundance studies. These additional probes will no doubt lead to a more complete understanding of the nature of element and star formation over the history of the Universe. ■

John Cowan is in the Department of Physics and Astronomy, University of Oklahoma, Norman, Oklahoma 73019, USA.
e-mail: cowan@mail.nhn.ou.edu

1. Fields, B. D. & Olive, K. A. *Astrophys. J.* **516,** 797–810 (1999).
2. Sneden, C. & Cowan, J. J. *Science* **299,** 70–75 (2003).
3. Shetrone, M. *et al. Astron. J.* **125,** 684–706 (2003).
4. Prochaska, J., Howk, J. C. & Wolfe, A. M. *Nature* **423,** 57–59 (2003).
5. Woosley, S. E. & Weaver, T. A. *Astrophys. J. Suppl. Ser.* **101,** 181–235 (1995).
6. Busso, M., Gallino, R. & Wasserburg, G. J. *Annu. Rev. Astron. Astrophys.* **37,** 239–309 (1999).
7. Sneden, C. *et al. Astrophys. J.* **496,** 235–245 (1998).