mechanism would involve the pseudogene DNA locus directly. For example, perhaps the 700-nucleotide region in the gene and pseudogene contains elements that, on binding certain proteins, repress transcription. In this model the repressor proteins would be limited in availability, so that *Makorin1-p1* would compete for repressor binding. These two models — RNA-mediated versus DNA-mediated — have mechanistic differences and could be tested.

Whatever the underlying mechanism, the work of Hirotsune *et al.*[5] is provocative for revealing the first biological function of any pseudogene. It challenges the popular belief that pseudogenes are simply molecular fossils — the evidence of Mother Nature's experiments gone awry. Indeed, it suggests that evolutionary forces can work in both directions. The forward direction is driven by pressures to create new genes from existing ones, an imperfect process that often generates defective copies of the original. But these defective copies need not be evolutionary dead ends, because pressures in the reverse direction could modify them for specific tasks. In the case of *Makorin1* and *Makorin1-p1*, the result of bidirectional selection is that one gene cannot exist without the other — an example of functional complicity between a perfected product of evolution and its derivative castaway. Might the pseudogene copies of other functional genes be similarly useful? ■

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Atmospheric chemistry

Burning domestic issues

Joel S. Levine

In the developing world much of the energy for heating, lighting and cooking comes from burning 'biomass', mainly wood. A first attempt has been made to quantify the resulting emissions to the atmosphere.

Almost a quarter-century ago, Paul Crutzen and colleagues[1] published pioneering work showing how the burning of biomass produces emission of a whole variety of trace gases. Since then there has been a growing realization of the environmental significance of this source of gases, and of associated particulate material, and the effects range from the local through the regional to the global. Biomass burning also influences the biogeochemical cycling of carbon and nitrogen compounds from the soil to the atmosphere.

Although most such burning occurs during human-initiated land clearance and changes in land use, a large component is due to the use of biomass fuels for domestic activities. That component has not previously been quantified. As they describe in the *Journal of Atmospheric Chemistry*, however, Ludwig and colleagues[2] have now provided some estimates, and the figures concerned are substantial.

Trace gases produced during biomass burning and released into the atmosphere include carbon dioxide (CO_2), carbon monoxide (CO), methane (CH_4) and non-methane hydrocarbons, hydrogen (H_2), nitric oxide (NO), ammonia (NH_3), methyl chloride (CH_3Cl) and sulphur species[3]. Carbon dioxide and methane are greenhouse gases that lead to global warming. Nitric oxide and sulphur species lead to the photochemical production of nitric acid and sulphuric acid, two of the main components of acid precipitation. Methane, carbon monoxide and nitric oxide bring about the photochemical production of ozone in the troposphere. Ozone is a pollutant and irritant, as well as a greenhouse gas.

Figure 1 **Domestic duty — an Ethiopian villager with firewood collected for cooking.**

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In studies of this topic, it is usual to divide burning into the following components: forests (tropical, temperate and boreal); savannas; agricultural waste left after harvesting (cereals' stubble, for instance); and fuel wood for domestic heating and cooking. For the first three components, the geographical distribution and area burned are key parameters in calculating the amount of gases and particulates released into the atmosphere. Although there has never been a dedicated satellite to monitor and quantify burning, satellite instrumentation designed for other purposes has allowed identification of the location of active fires and burned scar areas in forests, savannas and agricultural regions[4]. Space-based measurements can provide little information on the fourth component. But Ludwig *et al.*[2] point out that the use of fuel wood, charcoal and non-woody biofuels for cooking, heating and lighting is a daily event for about half of the world's population, mostly in the developing world (Fig. 1), and they have produced some detailed estimates of the resulting emissions.

That task required two types of information: data on the consumption of biomass fuels, and data on the emission of gases and particulates per unit quantity of those fuels (the emission factors). Ludwig *et al.* collected the limited published data on the first topic, and in assessing the second they performed a series of laboratory measurements of the emission factors of domestic biomass burning. To estimate the contribution to the global inventory of trace-gas emissions, they assumed that 80% of domestic biomass burned is wood, 15% is agricultural residue, 2.5% is dung and 2.5% is charcoal. Finally, they assumed that about 85% of the domestic emissions are taking place in the developing countries of Asia, Africa and Latin America.

As Ludwig *et al.* themselves say, the calculations have a high degree of uncertainty. Nonetheless, the figures — given here in teragrams (1 Tg is 10^{12} grams, or 10^6 tonnes) — are illuminating. The estimated annual global release through domestic biomass burning is 1,495 Tg of carbon in the form of CO_2, 141 Tg of carbon in the form of CO, and 2.54 Tg of nitrogen in the form of NO. These are significant proportions of the annual global production of these environmentally important gases: 17% of total CO_2, 13% of total CO and 6% of total NO. But as the authors point out, the estimated CO_2 release is not necessarily a net emission, as it depends on the sustainability of wood fuels. The use of agricultural residues and dung can be assumed to be 100% sustainable and

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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. ■

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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. ■

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