those for Galactic-halo stars, it is possible to test for a common origin. The inner-halo stars fail this comparison spectacularly: the satellite galaxies are systematically much younger, so the inner halo does not seem to have been formed by late aggregation of many small satellite galaxies.

That said, the real test of late-accretion models involves the stars of the outer halo, because it is out there that fluffy little galaxies will be shredded by Galactic tides, during the many mergers predicted by CDM theory. Stephens[1] provides the first high-quality results for a useful sample of stars with indisputable outer-halo orbits. Surprisingly, these stars are indistinguishable, in both their relative and absolute distributions of iron and α-elements, from the stars of the inner halo. The similarity in the absolute distributions is intriguing, as it is at odds with all simple models of galaxy formation in which a gaseous galaxy collapses slowly, forming stars in dense, short-lived gas clouds during the collapse. Such models predict that the outermost stars form earlier, on average, and so should have lower abundances of all the elements, because they formed before there had been time for many element-creating supernovae. The similarity of the relative abundances, as outlined above, is hard to reconcile with late-accretion models.

The most straightforward interpretation of all the relevant data on halo stars, including the new results from Stephens, is that the first significant star formation began in an extended but somewhat centrally condensed region, in a large number of gas clouds. Moreover, the beginning of star formation must have been synchronized within a period of 1 Gyr or so, across a region the size of the present Milky Way halo. This is not impossible, considering that a typical halo gas cloud will cross the entire halo diameter (roughly 50,000 light years) twice in that time, allowing for at least one star-forming collision. These clouds must have been sufficiently massive to survive one or more generations of star formation, supernovae and chemical-element enrichment. Whether it is more appropriate to call this inhomogeneous collapse, rapid early merger activity, or some other popular model, is perhaps more relevant to linguistics than to astrophysics. Perhaps, over the rest of the history of the Universe, a few dwarf galaxies — in much smaller numbers than predicted by current CDM models — strayed close to and were captured by the Milky Way, a process that continues today. □

Gerry Gilmore is at the Institute of Astronomy, University of Cambridge, Madingley Road, Cambridge CB3 0HA, UK.
e-mail: gil@ast.cam.ac.uk

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Microbiology

What's eating the free lunch?

Gary J. Olsen

If there is a free lunch to be had, someone (or something) will eat it. Inspired by faith in this principle, researchers have analysed the chemical energetics of many combinations of naturally occurring oxidants and reductants. Then, for each combination that is energetically favourable, they have sought an organism that exploits the reaction for its growth. Such searches have not always been successful. For example, over 20 years ago it was asserted that an organism that can use nitrite to oxidize ammonium anaerobically, in the so-called anammox reaction $NH_4^+ + NO_2^- \rightarrow N_2 + 2H_2O$, was 'missing' from nature[1].

However, the inability to cultivate a particular type of organism is no proof that it does not exist. Indeed, in this case, perseverance has been rewarded — on page 446 of this issue[2], Strous *et al.* describe the cultivation (in an enriched, but still mixed, culture) and partial characterization of a long-sought anammox organism. The results are of both scientific and practical value. Scientifically, there is the general question as to why nature is so good at producing organisms to exploit almost every free lunch, and, more specifically, the matter of how the organism deals with some highly reactive intermediates in the reaction. On the practical side, the organism might be used to lower the fixed nitrogen content of waste waters, a major concern in freshwater environments.

So what is this organism? Strous and colleagues' comparisons of molecular sequence data (ribosomal RNA genes) indicate that it is a distant relative of the planctomycetes, a group that includes the obscure genera *Planctomyces*, *Pirellula*, *Gemmata* and *Isosphaera* (see their Fig. 3 on page 448). Although planctomycetes belong to the Bacteria[3], they have some unusual features: cell division by budding (reminiscent of some yeasts), complex internal membrane structures (reminiscent of eukaryotes) and cell walls that lack peptidoglycan (reminiscent of Archaea)[4]. Even though the anammox organism is only distantly related to previously cultivated planctomycetes, it also divides by budding and has internal membranes. (The cell-wall composition is not reported.) Strous *et al.* speculate that the membrane structure might protect the cell from the reaction intermediates hydrazine (a good rocket fuel) and hydroxylamine (a

100 YEARS AGO

An ingenious machine for printing in colours, invented by Mr. Ivan Orloff, chief engineer and manager of the Russian Government printing works at St. Petersburg, has just been set up in London, and a company has been formed to develop the use of the machine for supplying coloured illustrations for periodicals and books. In colour printing by the ordinary method the successive colours are applied one at a time as the preceding one becomes dry. By means of the Orloff machine the whole of the colours required in a picture are printed at a single turn of the cylinder. If the picture has to be printed in, say, four colours, four separate blocks are arranged around the curved surface of the cylinder. As each block passes a particular point, the roller carrying the colour required by the block is made to fall upon it by a system of cams. Each block thus receives the coloured ink intended for it in the course of a revolution of the cylinder. … The results are very effective, and the "register" is perfect, no matter how many colours are used. The machine appears to mark a distinct development of methods of printing in colours.

From *Nature* 27 July 1899.

50 YEARS AGO

Luminous night clouds were observed in the northern sky in Scotland on the nights of July 9–10 and July 10–11, the extensive display showing characteristic wave structure in the early morning of July 11 being quite magnificent. Brilliantly blue–white in colour, the night clouds appeared about half an hour after sunset in a sky almost clear of normal cloud, were most brilliant during the hour after midnight and faded in the growing light before sunrise. … These rare clouds, which are observed only in summer and in middle latitudes, were first studied by Jesse and later by Störmer using his auroral network. … Occurring at heights of about 80 km., they provide valuable information concerning air movement at that level. On the evidence of their colour, it is generally believed that they consist of fine dust of cosmic or volcanic origin. It is significant that the present manifestation followed by a few days after an eruption in the region of the Canary Islands.

From *Nature* 30 July 1949.

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good mutagen), but this seems unlikely as both of these chemicals readily cross membranes. For now, we neither know the function of the membranes, nor the mechanisms of cellular protection.

In contrast to these unifying structural features, the metabolism of the anammox organism differs dramatically from that of the other planctomycetes[2,4]. The organism is a lithotroph, deriving its energy from inorganic compounds (ammonium and nitrite); other planctomycetes derive their energy from the oxidation of organic compounds. It is also an autotroph, able to fix carbon dioxide for its cellular carbon; other planctomycetes obtain their carbon by assimilating organic molecules. And it is anaerobic, respiring nitrite; the other planctomycetes are aerobic, respiring oxygen (although *Pirellula* species can also respire nitrate). These differences emphasize the tremendous metabolic diversity in related microorganisms.

Physical and biological reactions provide many potential sources of energy. The question is whether organisms can exploit those sources before they are dissipated by physical processes. To use an energy source, an organism must first be able to catalyse all or part of the path to equilibrium (an ability to eat the food); second, it must have a method to couple the equilibration with some biologically useful process or reaction (an ability to digest the food). Can evolution produce every useful metabolism? Are there limits on the inventiveness of life, or is everything possible through evolution?

I suspect that there are limits, but evolution is opportunistic and we easily underestimate the opportunities. If a resource is available to a large population (giga-Petri-dish-size experiments) for a long period of time (tens or hundreds of mega-graduate-student tenures), much can happen. Natural selection is powerful, and we do not see its countless failures. In addition, evolutionary resources transcend organismal and species boundaries; physiological capabilities can be drawn from any of thousands of microbial species by dividing steps of a reaction among two or more organisms in the community or by passing genes among organisms. In this regard, Strous *et al.* find that the anammox organism must be cultivated with other cells. The contribution of these neighbouring organisms is unknown, but it is not part of the anammox reaction as such.

We can push the limits of the free-lunch idea. An observation reported last year is that, in the hydrothermal-vent environment of organisms such as *Methanococcus jannaschii*, the synthesis of the more hydrophobic amino acids is energetically favourable[5]. For example, the synthesis of methionine from ambient H_2, NH_3, CO_2 and H_2S has a net free-energy of about -175 kJ mol^{-1}. That is, unlike ourselves, or *Escherichia coli*, *M. jannaschii* could in principle synthesize methionine and several other amino acids with no input of cellular energy; in fact it could make an energetic profit. Thinking about it naively, why shouldn't these organisms, or others in comparably highly reduced environments (mostly due to high H_2), have discovered that they can have a free lunch by making certain amino acids (E. L. Shock, personal communication)? At present, we have no answers. But given the existence of the anammox organism, and of others that exploit 'unusual' resources, it seems that we need to broaden our thinking, lest we overlook some very exciting biology. □

Gary J. Olsen is in the Department of Microbiology, University of Illinois, Urbana, Illinois 61801, USA.
e-mail: gary@phylo.life.uiuc.edu

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Condensed-matter science

Magnetic phases to order

Neil Mathur

Condensed-matter physics met chemistry head-on at a workshop in Russia earlier this month*, where an impressive array of experimental and theoretical evidence showed that phase separations occur over a variety of length scales, and that the various states of matter that arise can be both physically and chemically tuned.

Complex magnetic oxides, such as manganites of the form $(La,Pr,Ca)MnO_3$, can be ordered or disordered over different length scales. A fascinating range of spin, charge and orbital states can thus exist to different spatial extents. Various combinations of these states might order, disorder or melt to become dynamic. Chemists might look at the short-range correlations between electronic spins, charges and orbitals (bonds). These can collectively produce long-range effects leading, for example, to new structural symmetries (Fig. 1a). Long-range correlations can also lead to metallic behaviour (bands), ferromagnetism (the spontaneous alignment of magnetic spins) and charge-ordered stripes. This is truly the stuff of condensed-matter physics.

Phase separation is a hot topic in complex magnetic-oxide science[1]. But length scales matter. Macroscopic phases of ferromagnetism and antiferromagnetism (where spins spontaneously align antiparallel) might each extend over many tens of nanometres[2] (Fig. 1c), whereas the charge-ordered stripes that occur in certain manganites represent

**International Workshop on Spin, Charge and Orbital Ordering in Complex Magnetic Oxides*, Dubna, Russia, 1–3 July 1999.

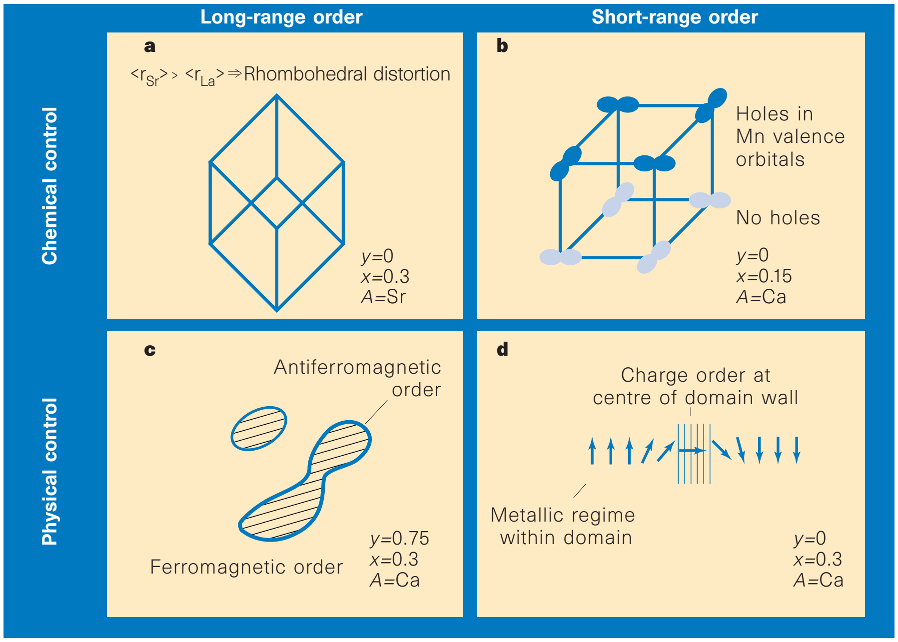

Figure 1 **Long-range and short-range order may be significantly varied in the $(La_{1-y}Pr_y)_{1-x}A_xMnO_3$ system by chemical and physical means.** a, **Chemical strain is introduced by replacing La with larger Sr atoms, producing a rhombohedral lattice distortion.** b, **Varying the ratio of La:Ca, x, leads to an unusual layered structure when $x = 0.15$, with every other microscopic layer containing no charge carriers.** c, **Physical control is demonstrated by applying a magnetic field B in the range 0.1 Tesla $< B < 1$ Tesla to produce a mixture of long-range ferromagnetic and antiferromagnetic order.** d, **A thin-film device can be used to impose an artificial magnetic twist in a continuous ferromagnetic crystal.**

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