Into the heart of darkness

Karl Gebhardt

The Milky Way, like other galaxies, is thought to harbour a black hole at its centre. The remarkable observation of a star in close orbit around the Galactic Centre is the first firm evidence that this is so.

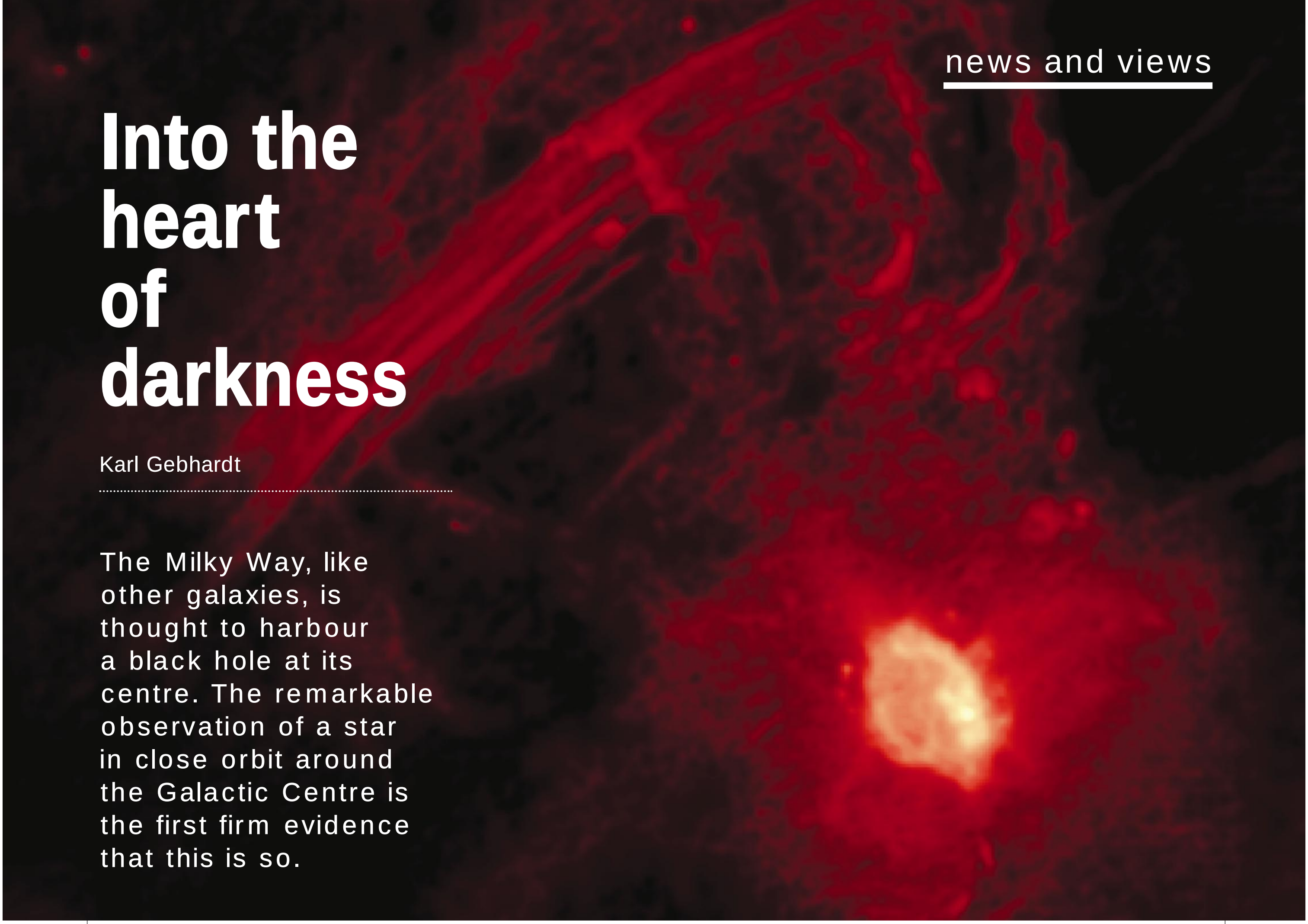

Figure 1 **Journey to the centre of the Galaxy. This image, taken by the Very Large Array of ground-based telescopes at radio wavelengths, shows a bright source at the centre of the Milky Way that was thought to surround a black hole. From their observations of a star in orbit around the Galactic Centre, Schödel *et al.*[1] conclude that there is indeed a supermassive black hole in this region. The structure known as the Galactic Centre Radio Arc (upper left) is believed to be generated by hot plasma flowing along lines of magnetic field.**

F. YUSEF-ZADEH/VLA/NRAO

Reporting on page 694 of this issue, Schödel *et al.*[1] describe the first observation of a nearly complete orbit of a star around the black hole at the centre of our Galaxy, the Milky Way. We have long been able to trace the movement of planets in our own Solar System, and astronomers are now beginning to observe planetary orbits in other stellar systems[2], but this is the first time that an orbit has been detected on the galactic scale. The sheer size of galaxies normally makes the detection of such movement impossible within a human lifetime. For example, our own Sun takes 230 million years to circle the Milky Way. The star that Schödel *et al.* report on will complete its orbit around the central black hole of our Galaxy in a mere 15 years — lightning speed on the grand, slow scale of the Universe.

That we are now able to watch the orbit of a star across our Galaxy is only one of several important implications of Schödel and colleagues' findings. For many years now, astronomers have been reporting that supermassive black holes — more than a million times the mass of the Sun — exist in nearly every galaxy[3]; scientists now even have data that suggest that black holes also occupy the centres of smaller stellar systems called globular clusters[4,5]. But despite decades of research and discovery, no one had found conclusive evidence that supermassive black holes exist.

The problem was that astronomers had never been able to observe the centres of galaxies closely enough to rule out other possibilities, such as a collection of neutron stars masquerading as a central black hole[6]. But these new data probe the Galactic Centre more closely than ever before. The matter density that Schödel *et al.*[1] infer from the details of the star's orbit is inconsistent with the presence of neutron stars, or other more exotic objects. The only compelling explanation is that there is a supermassive black hole lurking there. These results are the best evidence yet that supermassive black holes are not just theory, but fact.

The technique used by Schödel *et al.* to measure the stellar orbit is also impressive. Their success shows the true power of a relatively new observing tool, adaptive optics imaging[7]. Starlight reaching ground-based telescopes becomes blurred as it travels through the Earth's atmosphere. In an adaptive optics system, the distortions in the incoming beam are measured, and electronic signals sent to a deformable mirror. In response, the mirror can rapidly change its shape to correct for those distortions as it reflects the starlight. The blurring effects of the atmosphere are removed almost completely from the data and thus ground-based observations can be as sharp and informative as those from space-based telescopes.

Using this new technology, we are now able to see images that are up to 20 times sharper than they once appeared, making it possible to differentiate individual stars in the crowded stellar regions at the centre of the Milky Way (Fig. 1). Faint stars that were practically invisible can now be isolated, and more stars in orbit at the very centre of our Galaxy could be found. Measuring the orbits of these stars should provide even stronger evidence in favour of a black hole, and it should eventually be possible to test the predictions[8] of general relativity using stars that pass even closer to the black hole. The power of adaptive optics may also enable us to determine how material is funnelled into a supermassive black hole or, in the case of the black hole in the Milky Way, why so little matter is actually consumed by it[9].

Although the main point of interest for the layperson may be the proof that black holes are real, scientific research is more concerned with gathering the best possible data and determining the most accurate results. The black hole in our Galaxy does not have the best-determined mass, but with continued observations, following those of Schödel *et al*. and others[10], it will soon be the best constrained. The exact value of its mass has important implications for understanding how our black hole compares with those at the centres of other galaxies[11]. We still have a way to go, but for this black hole the future is bright. ■

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Microbiology

All in the packaging

Edward F. DeLong

Certain bacteria generate highly toxic intermediates as part of their metabolism. Membranes with an unprecedented lipid composition and structure apparently meet the need for containment.

Lipid membranes form the major barrier that distinguishes 'self' from 'non-self', and they are essential for keeping cellular components inside a cell and toxins outside it. They are also active participants in the energy and transport processes necessary for cell growth and survival. The cells of eukaryotes (all animals, plants, protists and fungi) also house membrane-bound structures called organelles, which have specialized functions — for example, energy production in mitochondria and photosynthesis in chloroplasts.

At first glance, the fundamental composition of membrane lipids among life's three domains (eukaryotes, bacteria and archaea) seems much the same and rather simple. In eukaryotes and bacteria, the chemical make-up of the predominant membrane lipids follows a common theme. Generally, they consist of two fatty acids, each joined by an ester group to a phosphorylated glycerol backbone. In the archaea, the arrangement is somewhat different, consisting of two isoprenoid units bound to a glycerol backbone by a very stable ether linkage.

Now, on page 708 of this issue, Damsté and collaborators[1] report on the presence and structure of bizarre bacterial lipids never before seen in nature. These lipids, called ladderanes, occur in organelle-like structures in an unusual bacterium that makes its living by consuming ammonia in the absence of oxygen.

The bacterial lipids discovered by Damsté *et al.*[1] deviate considerably from those normally found in bacteria and archaea. Some of the lipids are bound to a glycerol backbone by an ether linkage, which is unusual but not unprecedented in bacteria. More striking are the core lipid structures that have never been seen before in any organism. One contains three consecutive four-carbon (cyclobutane) rings, the terminus of which is attached to a six-carbon (cyclohexane) ring. This arrangement has the appearance of a staircase-like structure — hence the ladderane moniker. A simple modification of the terminal cyclohexane ring results in the other proposed lipid structure, which consists of five cyclobutane rings arranged in a ladder-like array. Further, Damsté *et al.* show that the unique structure, biophysical properties and intracellular location of the lipids are likely to be essential to the metabolic function of the bacteria concerned.

To appreciate the significance of the ladderane lipids, a little information about the microbes containing them is helpful. The ladderane-containing bacteria are distantly related to other microbes belonging to the order Planctomycetales[2]. These bacteria have a highly unusual physiology, in that they live by consuming ammonia in the absence of oxygen. As a consequence of ammonia oxidation, nitrite (NO_2^-) is reduced, nitrogen gas is generated, and carbon dioxide is converted ('fixed') into organic carbon[3–6]. The overall process, referred to as 'anammox', is the central energy-generating pathway for these microbes:

$$NH_4^+ + NO_2^- \rightarrow N_2 + 2H_2O.$$

The biological feasibility of this process was predicted decades ago based on thermodynamic considerations[7]. But only recently was it actually shown to occur, in a wastewater treatment plant, by Keunen and colleagues[8]. Anammox is of great practical interest, given the need to remove nitrogen

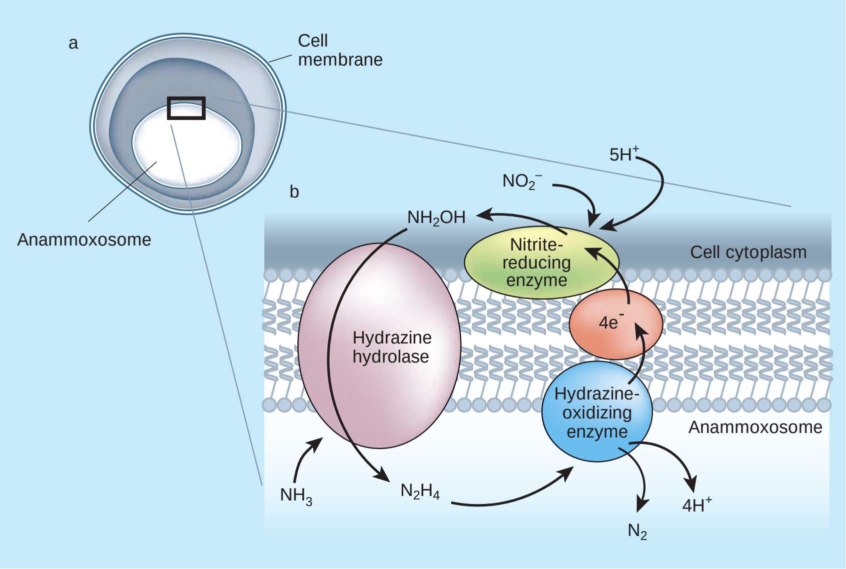

Figure 1 **Bacteria with a difference.** a, **A simplified depiction of the anammox microbe, showing the anammoxosome. This is the organelle-like structure in which the energy-generating process involving the combination of ammonia with nitrite takes place.** b, **The anammoxosome membrane, which consists of the ladderane lipid bilayer identified by Damsté *et al.*[1], and the anammox reaction pathway. Intermediates in the cycle are hydrazine (N_2H_4) and hydroxylamine (NH_2OH), which are highly toxic. The dense, impermeable membrane may serve to contain them. (Adapted from refs 1 and 6.)**