animals. The benthic fish *Ipnops murrayi* has the surface of its flattened snout covered in naked retinas, and many crustaceans from deep water seem to have converged on the same drastic strategy for finding the vague direction of very dim light. Certainly in *Bythograea*, and probably more generally, it seems that such eyes are not degenerate but are well adapted to the prevailing light conditions. ■

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1. Jinks, R. N. *et al. Nature* **420,** 68–70 (2002).
2. Van Dover, C. L., Szuts, E. Z., Chamberlain, S. C. & Cann, J. R. *Nature* **337,** 458–460 (1989).
3. White, S. N., Chave, A. D. & Reynolds, G. T. *J. Geophys. Res.* **107,** 1–13 (2002).
4. Land, M. & Nilsson, D.-E. *Animal Eyes* (Oxford Univ. Press, 2002).

Astronomy

Twinkle, twinkle, neutron star

Cole Miller

Neutron stars, as the name suggests, are mostly made of neutrons. But the cores of these tiny, dense stellar leftovers might conceal new states of matter, including strange matter. The light from these stars holds the key.

Neutron stars, formed during the death throes of massive stars, are among the most exotic objects in the Universe. They are the size of a city but typically contain at least 40% more mass than our Sun. As a result, their core density is several times the density of an atomic nucleus. In principle, this means that neutron stars may be our only window on the properties of matter beyond nuclear density. But in practice, this window has been hard to open, because spectroscopic information — the cornerstone of astronomical data — is exceedingly difficult to obtain for neutron stars. As Cottam *et al.*[1] report on page 51 of this issue, and as Sanwal *et al.*[2] discuss in the *Astrophysical Journal*, this situation may be about to change.

The properties of extremely dense matter have long been a focus of research in nuclear physics. The most mundane possibility is that matter simply becomes very neutron-rich at high densities. Even then, the extraordinary densities in neutron stars lead to the onset of phenomena such as superfluidity and superconductivity — the latter at a transition temperature of around 10^9 K, making neutron stars the true high-temperature superconductors of the Universe. But it has also been suggested that in neutron-star cores, unique forms of matter may dominate. These include Bose–Einstein condensates of subatomic particles such as pions and kaons; enormous 'bags' of the elementary particles known as quarks; and so-called strange matter[3,4].

Learning about dense matter from neutron stars is challenging because observations only provide indirect information. One approach is to constrain the values for the mass and radius of individual stars. If high-density matter is especially compressible (as it will be if exotic components are present), the star will be comparatively small for its mass. The presence of exotic matter also lowers the maximum stable mass for a neutron star. For example, data from the satellite-based Rossi X-ray Timing Explorer suggest[5] that the neutron star 4U1820−30 has a mass 2.2 times that of the Sun, which is probably too high for it to contain exotic matter; but the complicated properties of this source make the mass estimate highly uncertain. If a neutron star has a mass of around 1.4 solar masses, the range of theoretically allowed radii[6–8] is roughly 7–15 km, although this range is more restricted if one considers only standard models based on modern nuclear scattering data[9]. Although the masses of many neutron stars have been estimated from observations of binary orbits, measurements of their radii have proved elusive.

How can astronomers measure the size of an object that is probably just 10 km in radius but more than 10^{16} km away? One solution is high-resolution spectroscopy. Each type of atom or molecule radiates at particular energies, and so can be identified in the spectrum of light from a star. The effects of gravity cause the observed energies of the spectral lines to be shifted to lower values, by a factor of $1/(1+z)$, where z is called the redshift. This redshift depends on the ratio of the star's mass to its radius, and so measuring the shift in spectral lines provides indirect information about the stellar radius. Returning to the example of a neutron star with a mass of 1.4 solar masses, radii of 15 km down to 7 km correspond to $z=0.18$–0.56; $z=0.30$ for a canonical radius of 10 km. But X-ray instruments did not have the sensitivity and resolution needed to detect such redshifts, until now.

The new results have been achieved through the remarkable spectroscopic capabilities of the space-borne Chandra X-ray Observatory and X-ray Multi-Mirror (or XMM–Newton) instruments. Sanwal *et al.*[2] report Chandra observations of the young isolated neutron star 1E1207.4−5209. They have found two absorption lines in the spectra, at energies of 700 and 1,400 eV (electron volts), which they interpret as the signature of singly ionized helium in a strong magnetic field. The implied redshift is 0.12–0.23. As well as gravity, the magnetic field (around 10^{12} gauss) has a large effect on the line energies. But because the field strength is not known accurately, Sanwal *et al.* cannot be sure that they have correctly identified the lines, and neither can they conclusively rule out other interpretations (such as those based on cyclotron features).

This is where the results of Cottam *et al.*[1] come into play. They obtained XMM–Newton observations of EXO0748−676, a neutron star that is accreting gas from a lower-mass star. For various reasons, the neutron stars in such systems are thought to have surface magnetic fields of around 10^7–10^9 gauss. Although staggering by terrestrial standards (the Earth's magnetic field is just 1 gauss), these fields are too weak to have a significant effect on atomic spectra at energies higher than 100 eV. So it is easier

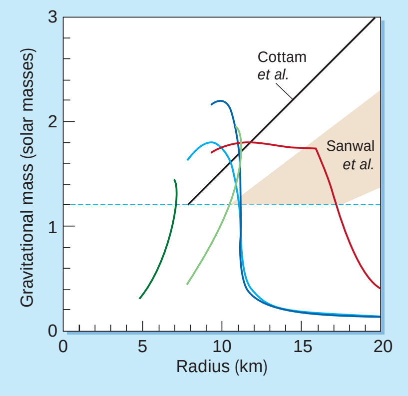

Figure 1 **The structure of neutron stars. The gravitational mass and the radius of a neutron star are both related to the 'redshift' that can be measured in the spectrum of light emitted by the star. The range of possible values for mass and radius is shown for various models of the neutron-star interior: stars containing strange matter (light- and dark-green curves); stars made of normal matter (light and dark blue); and stars whose cores become a Bose–Einstein condensate of pions if their mass is higher than 1.8 solar masses (red). The blue dashed line represents a conservative lower limit, at 1.2 solar masses, for the mass of a neutron star formed from a supernova. From the redshifts measured for two different neutron stars, Cottam *et al.*[1] and Sanwal *et al.*[2] have derived the allowed values of mass and radius (black line and shaded region respectively) and find that they are not consistent with some models of strange-matter stars. The mass of neither source is known at present; accurate mass measurements would clearly strengthen the constraints considerably.**

to determine the redshift from this star's spectrum than it is from that of a strong-field neutron star.

Cottam *et al.* observed EXO0748−676 during a series of 28 X-ray bursts — the flashes from thermonuclear fusion that occur when sufficient hydrogen and helium has piled up on the star's surface. They found three strong spectral lines, which they identify as the signatures of 25-times-ionized iron (Fe XXVI in astronomical nomenclature), Fe XXV and O VIII. The inferred redshift for all three is 0.35, which defines a range of possible values for the mass and radius of this star (Fig. 1). Such identifications should always be handled with care, because there are in principle many atomic species and many transitions to check. But Cottam *et al.* make a good case that these are the most probable sources of these lines. If the identifications are correct, the redshift is exactly in the range expected for a star made of normal neutron matter, and doesn't fit the models for the most compact strange-matter stars[8], although there is still room for exotic components (Fig. 1).

The importance of these results inspires caution. It would be good to see lines measured with self-consistent redshifts from more neutron stars, to guard against the possibility that the lines have been misidentified in these two sources. Moreover, constraints on models for high-density matter would be strengthened considerably if both the mass and gravitational redshift were measured for other neutron stars. In any case, high-resolution instruments such as Chandra and XMM–Newton are dramatically fulfilling their promise as sensitive probes of matter in extreme environments. ■

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1. Cottam, J., Paerels, F. & Mendez, M. *Nature* **420,** 51–54 (2002).
2. Sanwal, D., Pavlov, G. G., Zavlin, V. E. & Teter, M. A. *Astrophys. J.* **574,** L61–L64 (2002).
3. Shapiro, S. L. & Teukolsky, S. A. *Black Holes, White Dwarfs, and Neutron Stars* (Wiley–Interscience, New York, 1983).
4. Alcock, C., Farhi, E. & Olinto, A. *Phys. Rev. Lett.* **57,** 2088–2091 (1986).
5. Zhang, W., Smale, A. P., Strohmayer, T. E. & Swank, J. H. *Astrophys. J.* **500,** L171–L174 (1998).
6. Arnett, W. D. & Bowers, R. L. *Astrophys. J. Suppl.* **33,** 415–436 (1977).
7. Zdunik, J. L. *Astron. Astrophys.* **359,** 311–315 (2000).
8. Dey, M., Bombaci, I., Dey, J., Ray, S. & Samanta, B. C. *Phys. Lett. B* **439,** 123–128 (1998).
9. Akmal, A., Pandharipande, V. R. & Ravenhall, D. G. *Phys. Rev. C* **58,** 1804–1828 (1998).

Protein folding

With a little help…

Charles L. Brooks III

Experiments and computer simulations are converging in their exploration of the timescales on which protein folding occurs. Such developments are a promising way forward in molecular biophysics.

From a cast of thousands, and the experiments of a few, a new combination of computer simulation and experiment to investigate protein folding has emerged. This work, described by Snow *et al.* on page 102 of this issue[1], shows that the key events in the folding of a small artificial protein can be directly examined by atomic-level computer simulation. Moreover, the results are in general agreement with experiments performed under analogous conditions.

Snow *et al.* have brought the distributed computing machinery embodied in the Folding@home project[2,3] to bear on the direct simulation of folding of small, though conformationally rich, polypeptides. The polypeptides are based on a specially designed mini-protein named BBA5 — which, for all its small size, nonetheless adopts a canonical native fold, the α-helix and β-hairpin. The authors look at the folding of BBA5 mutants (that is, proteins with sequences that differ from BBA5 by substitutions of one or two residues), and show that the folding occurs on a timescale of 1–10 μs at temperatures near 300 K. The general agreement between experiment and simulation for this system suggests that current methods for describing atomic interactions by computer simulation (with 'force fields' and molecular-dynamics methods) are adequate for exploring the timescales and energies of folding.

Folding is a highly complex, structure-organizing process, in which a chain of amino acids passes through several stages before the protein concerned — say, an enzyme — reaches its final folded and active form. Many small proteins adopt their folded state from a diverse set of less structured conformations by crossing a single barrier (transition state) in a nearly all-or-none, two-state fashion on timescales ranging from a few microseconds to milliseconds and longer. Progress in experimental methods during the past few years provides the tools to explore folding processes on the fastest of these timescales[4]. On the other hand, even the fastest timescales are very long compared with routine times accessed in molecular-dynamics simulations of proteins.

The problem, then, in computer simula-

100 YEARS AGO

The Health Department of the City of London has had a number of samples of ice-creams bacteriologically examined. A large proportion of the samples were found to be unsatisfactory; in several micro-organisms were very numerous, while in some virulent organisms of the *Bacillus coli* type were present; one contained pyogenic organisms and produced abscesses in guinea-pigs, and another contained an anaërobic organism, perhaps the bacillus of malignant oedema. Many of the ice-creams from which samples were examined had set up gastro-enteritis in boys employed by the Post Office.

ALSO…

New fields for research are continually opening up; the last illustration of this is the discovery by Prof. G. Elliot Smith that it is possible to map the convolutions of the brains of non-mummified ancient Egyptians. The brain is naturally preserved in the vast majority of the bodies in Egyptian cemeteries from predynastic to recent Coptic, the favourable conditions being burial in dry soil and removal from all direct access to the air... In a memoir, which will be published in a short time, he intends to give a full account of the structure of the brain in the predynastic and protodynastic Egyptians.

From *Nature* 6 November 1902.

50 YEARS AGO

The Nobel Prize for Physiology and Medicine for 1952 has been awarded to Prof. Selman Abraham Waksman… for his discovery of streptomycin, the first effective antibiotic against tuberculosis. Prof. Waksman was born in 1888 in Priluka, a small town in the Ukraine, emigrated to the United States in 1910 and became a naturalized citizen there in 1915. The whole of his scientific life since 1911 has been spent at Rutgers University and has been devoted to the study of microbiology, and particularly to that group of soil micro-organisms which are frequently spoken of as ray fungi and belong to the genus *Actinomyces* or *Streptothrix*. Following the discovery of penicillin, which is fully effective only against Gram-positive bacteria, Waksman and his collaborators began, in 1939, a systematic search for an antibiotic active against Gram-negative bacteria and found it, in 1944, in streptomycin, a metabolic product of *Streptomyces griseus*… They also showed that streptomycin is highly active *in vitro* against *Mycobacterium tuberculosis*.

From *Nature* 8 November 1952.