ordinary X-ray pulsars are powered by the matter that they accrete from a companion star. But, despite careful searches, no plausible companions have been identified around AXPs. Nonetheless, AXPs show persistent and strong X-ray emission, well above the level that can be supported by their store of rotational energy. The source of energy in these objects is mysterious, which is why these X-ray pulsars are called anomalous. The long rotation period of AXPs also suggests a family resemblance to SGRs.

According to the magnetar model devised by Thompson and Duncan, the decay of the intense magnetic field in a magnetar provides a source of energy and powers the radiation emission. By analogy with the Sun (Fig. 1), loops of magnetic field could occasionally reconnect, producing a flare. But in the case of magnetars, the field strength is $10^{14}$ times greater than that in the loops on the Sun, and the resulting flares are proportionally more intense. Furthermore, the strong magnetic field might move portions of the outer layer, or crust, of the neutron star — as though moving continental plates. Like earthquakes, a major flare could be followed by minor ones. Once the stress has built up once more, the reconnection process happens all over again, which explains the repetitive appearance of the flares.

There are, however, several issues still outstanding for the magnetar model. To start with, there is the problem of the evidence for strong magnetic fields in SGRs. From the spectra of emitted light, astronomers have been able to measure field strengths directly in a number of astrophysical objects, including the Sun and ordinary neutron stars. Yet there had been no such direct spectral evidence for SGRs: evidence for their strong magnetic fields came only indirectly, through their intense bursts of radiation. Second, the magnetar model postulates that both AXPs and SGRs are magnetars, and yet the two types of star seem quite different in that no bursts of radiation had ever been detected from AXPs. So although the case for SGRs as magnetars is plausible, for AXPs it has up to now been considerably weaker.

But during a routine monitoring programme using the Rossi X-ray Timing Explorer, Gavriil et al. 1 found bursts from an AXP. They argue quite persuasively that these bursts arise from the AXP and not from an unrelated source. This discovery at last establishes a strong link between AXPs and SGRs.

There is a plausible explanation for why the bursts from AXRs are fainter than those from SGRs, and thus harder to detect. AXPs tend to be located at the centre of supernova remnants, and so are undoubtedly young neutron stars. In contrast, SGRs are not associated with supernova remnants, implying that SGRs must be older than AXPs. It is possible that the crust of young neutron stars is more malleable or plastic, and thus AXPs may be unable to support supermagnetic loops that reconnect to generate the intense bursts. But as AXPs age, the crust could become less plastic and consequently capable of supporting strong magnetic loops — up to a point.

Gavriil et al. 1 also made spectroscopic measurements. They found that the bursts have a strong feature in their spectrum that can reasonably be interpreted as being due to proton synchrotron in the intense fields of a magnetar. A similar spectral feature has recently been reported for an SGR. Both detections await firm confirmation — and will motivate many further observations — but if they are real then we have direct evidence for strong field strengths.

It seems that magnetars do exist. Astronomers can feel quite satisfied to have postulated, discovered and confirmed a new class of cosmic object. And physicists will be excited by the possibilities of magnetars: where magnetic field strengths exceed about $10^{14}$ G, all sorts of strange effects arising from the quantum theory of electrodynamics are potentially detectable (for example, the intense fields of magnetars could polarize the vacuum). Sensitive experiments could look for such effects and make good use of one of nature’s greatest laboratories.

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Global change

Oceanic action at a distance

Raja S. Ganeshram

Glacial intervals are characterized by low levels of atmospheric CO$_2$. A new explanation for that connection invokes nutrient export from the Southern Ocean to warmer waters at such times.

In the late 1980s came news of a spectacular discovery: that temperatures at Earth’s surface and levels of atmospheric CO$_2$ in the atmosphere fell and rose in tandem during glaciation-interglacial cycles. Since then, Earth scientists have been busy seeking explanations for the connection and much recent thinking has centred on oceanic controls on CO$_2$. Writing in Geophysical Research Letters and Global Biogeochemical Cycles, respectively, Brzezinski et al. and Matsumoto et al. take this line of investigation a step forward. Together the papers provide a new hypothesis, elegantly supported by a set of palaeoceanographic evidence and biogeochemical modelling, that could help account for much of the reduction in atmospheric CO$_2$ during glacial periods.

For some years, Milankovitch cycles — minute variations in solar radiation reaching the Earth due to changes in Earth’s orbit — were taken as an explanation for the pacing of the oscillations between glacial and interglacial intervals. But accounting for the large temperature shifts involved required further amplification within the Earth’s climate system. One analysis of air trapped in ice cores revealed that CO$_2$ had fallen and risen in tune with the glacial-interglacial rhythm, the finger pointed to the greenhouse effect exerted by changes in CO$_2$ as an amplifier.

Certain parts of the world’s oceans have an especially large influence on climate, the Southern Ocean — the waters around Antarctica south of the polar front — being one of them. Oceanographers have long recognized that reduced leakage of CO$_2$ from oceans to atmosphere in such areas could contribute significantly to the lower levels of atmospheric CO$_2$ in glacial periods. In today’s Southern Ocean, CO$_2$-charged, nutrient-rich deep waters reach the surface and release CO$_2$ to the atmosphere. This leak could effectively be plugged by an increase in biological production in the surface waters through fuller use of the available nutrients by phytoplankton, primarily diatoms. Increased production would transfer more CO$_2$ back to the ocean depths in the form of sinkingorganic particles.

Today, nutrients — particularly nitrate — that reach the sunlit surface ocean around Antarctica remain underused by phytoplankton because of a lack of the iron needed by their photosynthetic apparatus. But during glacial periods, the larger amounts of dust in the atmosphere should have increased the supply of iron, potentially alleviating the deficiency, increasing nutrient use and yielding a net transfer of CO$_2$ back to deep waters. Isolating the deep waters from the atmosphere by capping them with less-dense water at the surface (stratification) would have the same effect. With these ideas in mind, palaeoceanographers have been studying Southern Ocean sediments laid down in glacial times for clues to higher
100 YEARS AGO
Although the terms “ass” and, at any rate in Germany, “ox” (Ochs) are very generally applied to stupid persons, those who have observed the bovine and asinine genera know that this is an injustice to those animals... A donkey that was kept here learnt to open, not only the gate of its own field, but other gates. One day, having left its own abode, accompanied by two ponies, it went to another field half a mile off, opening three gates on the way, liberated the occupants of this field, a mare and her foal, and a yearling, old friends of the donkey’s, as they used to live together, and the whole party, which had been joined by a mastiff, proceeded to wander through the world.

About two miles from here the horses were recognised and secured, and the donkey eventually returned with the mastiff; but after this exploit it was thought advisable to get rid of the donkey, as being too zealously devoted to the cause of emancipation.

From Nature 11 September 1902.

50 YEARS AGO
Scientific Progress of April (40, No. 158, 193; 1952) contains an interesting and informative article by Prof. H. S. W. Massey entitled “Fundamental Particles”, the term which is applied usually to such entities as electrons, protons, etc. ... Turning next to the classification of the fundamental wave particles, Prof. Massey shows that the particles can be loosely separated into three categories, which he aptly terms “building stones” (electron, proton and neutron), “cements” (photon and pi-meson) and “bric-a-brac” (neutrino, mu-, V-, tau- and kappa-mesons).

The first two categories, as their names imply, are involved in the structure of matter, but the third, apparently, does not fulfil any important role in that respect. The properties of the various particles and the relations between them are briefly and clearly described, and it is evident that their number (now some twenty-four) is far too large for them all to be fundamental. Nevertheless, as Prof. Massey states, the discovery of new particles is still a prominent feature of modern physics, and thus, until some new fundamental advance or simplification is made on the theoretical side, not only to provide a basis for the “bric-a-brac” but possibly also to account for the more complete range of particles yet to be explored, the fundamental scheme of Nature must remain obscure.

From Nature 13 September 1952.

Nutrient utilization and biological productivity. But there have been puzzling.

Stable isotope ratios of nitrogen and silicon in organic and diatom remains, respectively, tell us about the nutrient status during the geological past. This is because diatoms’ use of nitrate (NO₃⁻) and silicic acid (Si(OH)₄) favours the uptake of the lighter isotopes, ¹⁵N and ³⁰Si. Diatoms become progressively enriched in the heavier isotopes, ¹⁴N and ³²Si, as the nutrients are depleted, and increased nutrient use should be reflected in their sedimentary remains as higher δ¹⁵N and δ³⁰Si. As shown in Fig. 1, sediment cores from the Southern Ocean have higher δ¹⁵N values in the glacial intervals, indicating increased NO₃⁻ uptake compared to that in interglacials. But the δ³⁰Si trends are quite the opposite: Si(OH)₄ use appears to have been lower during the glacials. Other arguments that invoke, for example, increased ocean stratification, could account for the higher δ¹⁵N but they fail to explain lower δ³⁰Si values. How can we reconcile the two different pictures of nutrient status painted by these two forms of proxy data?

On the basis of experimental results, Brzezinski et al. point out that the addition of iron dramatically alters the uptake ratio of NO₃⁻ and Si(OH)₄ by diatoms from as much as 4:1 to about 1:1. Given that ratios of these nutrients in the Southern Ocean today are 2:1, uptake with a ratio of 1:1 under iron-replete conditions, as might have occurred during glacial periods, would result in higher use of NO₃⁻ but relative underutilization of Si(OH)₄, a view that is consistent with the isotope data. Given this revised interpretation of the sediment records, did the Southern Ocean contribute to the drop in atmospheric CO₂ during glacial periods, Brzezinski et al. argue that it did, but not as a direct effect of CO₂ uptake in Antarctic surface waters. Rather, as Matsumoto et al. show in their modelling study, when ocean circulation patterns are taken into account, the consequences of this peculiar nutrient biogeochemistry are manifest further afield.

The waters of the modern Southern Ocean penetrate north as far as the subtropics, mainly as subsurface flow. If the flow paths were the same during glacial times, then the Pacific would have supplied the low-latitude ocean with water high in Si(OH)₄ and low in NO₃⁻. This would have pushed the phytoplankton community in these regions from domination by CaCO₃-secreting coccolithophores to domination by opal-secreting diatoms. Brzezinski et al. believe, and Matsumoto et al. demonstrate with their model, that such an ecological shift would have had a double effect on reducing glacial CO₂. First, diatoms have higher sinking rates than coccolithophores; their dominance would have resulted in the more efficient export of particulate organic matter to the depths, thus removing CO₂ from the surface waters. Second, the lowered ratio of CaCO₃ to organic carbon in sinking particles would also have lowered levels of atmospheric CO₂ because the resulting excess CO₃⁻ (alkalinity) in surface waters would have sequestered CO₂ by converting it to bicarbonate.

But did such a shift towards increased primary production by diatoms actually occur at low latitudes in glacial times? The answer is unclear; because of the telling indicator, accumulation of opal in sediments of glacial age, is not uniformly high in these regions. Increases are indeed seen in some areas. Declines are evident elsewhere, however, such as in the eastern tropical Pacific. This geographical variability may point to local changes in nutrient inputs as the main determinant of opal production.

The work of Brzezinski et al. and Matsumoto et al. provides a compelling case for the role of iron in regulating CO₂ levels, and highlights the importance of understanding the interactions between nutrient availability and biogeochemical processes in the Southern Ocean. Further research is needed to confirm these findings and to explore the full implications of these results for our understanding of past and present climate change.
sumoto et al. resolves the conflict generated by the proxy evidence for the nutrient status of the Southern Ocean at various times. But assessing the effects of their proposed mechanism on atmospheric levels of CO₂ during glacials, as well as the effects of other ideas that have been put forward, will require more evidence. We need a more synoptic view of past shifts in nutrient ratios, and a better understanding of the ecological response to such changes. Progress is being made, but the story isn't over yet.

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Optics

The light fantastic

Martin Hegner

Optical tweezers use light to manipulate tiny particles — but only one at a time. If the light in the tweezers is a ‘Bessel beam’, this problem can be overcome, creating some interesting experimental possibilities.

Optical tweezers have become a standard tool in many areas of science, such as colloid research and biological studies. On page 145 of this issue, Garcés-Chávez et al. report an extension of this technique that makes it possible to manipulate ensembles of particles simultaneously.

Light can exert force on dielectric (polarizable) particles through radiation pressure and refraction: light has momentum, and so light and matter can interact by changing momentum. Although these forces are small (of the order of 10⁻¹² newtons), they are sufficient to trap and manipulate micrometre-sized particles in a liquid environment. So far, optical manipulation of particles in different places at the same time has been possible only if the particles are in the same optical plane of view. Otherwise the problem is that the manipulating light beam will diverge around the first trapped particles, and then cannot be brought back to a focus within the short distance to the next set of particles. So experiments must be done in series, and this is very time-consuming. To speed things up, it would be better to work in parallel, manipulating particles held in multiple back-to-back compartments (such as a collection of biological-cell samples) at the same time with a single light beam.

Using a special kind of optical focusing to create a ‘Bessel beam’ of light, Garcés-Chávez et al. now provide the first demonstration of the manipulation of micrometre-sized particles in multiple planes. A Bessel beam (Fig. 1) is so called because the variation of its intensity follows the mathematical pattern known as a zero-order Bessel function. Thanks to its special optical properties, the bright central spot of the beam can re-form after passing an obstruction; the beam does not interfere with the obstruction and reforms only a few micrometres further on. Garcés-Chávez et al. show that even when a Bessel beam of light is partially obstructed by an object in the first fluid-filled compartment, particles in a second, spatially separated, fluid compartment can be manipulated using the same light beam and with the same precision. This has been impossible with the conventional optical manipulation techniques used so far.

The authors created a diffraction-free Bessel beam using simple lenses and a special conical lens called an axicon. The bright spot at the beam’s centre is non-diffracting, and so particles can be guided (made up of DNA and proteins) through the micro-dissection of chromatin (made up of DNA and proteins) through tiny openings or pores. For cell sorting, these tweezers are capable of manipulating many samples at once.

Figure 1. A Bessel beam. Light passing through a particular scheme of lenses can form a beam of light with a bright central spot and concentric rings of decreasing intensity — known as a Bessel beam, as its varying intensity is described by the zero-order Bessel function shown here. Garcés-Chávez et al. have used a Bessel beam to create optical tweezers capable of manipulating many samples at once.

The Bessel beam can be imagined as a single rod of light, pushing the trapped particles along its axis. The trapping can extend over a few micrometres, and particles can be held firmly in two dimensions. In contrast, a gaussian beam can hold particles in a stable, three-dimensional configuration, but the beam diverges quickly, so particles can only be guided for a few micrometres along the axis of such a beam.

Certainly, one of the most impressive applications of (gaussian) optical tweezers is in the study of molecular motors and polymer mechanics. These experiments have provided fresh insight into biochemical processes at the single-molecule level and are of great relevance in biology. The key to such experiments is in immobilizing the biological molecule of interest on the surface of a bead and attaching its interacting partner molecule to a second bead, which can then be trapped in three dimensions using infrared laser light. But particles or beads caught in a Bessel beam are constantly pushed along the beam axis, and so comparable studies using Bessel-beam tweezers are not yet possible.

It is foreseeable, however, that if a counter-propagating Bessel beam were applied, the particles’ forward motion could be stopped. Like balancing a rod on the tip of another rod, a stable three-dimensional trap between the beams could be established if the power of the beams were adjusted properly. Extending this idea to exploit the Bessel-beam tweezers’ ability to work on many particles simultaneously over considerable distance, patterns could be created from interfering Bessel beams, forming arrays of light spot that could be used, for example, to rotate microsystems, or to control lab-on-a-chip microstructures.

In biology, Bessel-beam tweezers could be used to sort the oval-shaped particles produced in the micro-dissection of chromatin (made up of DNA and proteins) through tiny openings or pores. For cell sorting, these tweezers are capable of more accurate guiding than systems used so far. The Bessel-beam technique will no doubt find application across a broad range of science.

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