100 YEARS AGO

THE BEST EDUCATION FOR AN ENGINEER

A study of the classics and a public school education are frequently regarded as synonymous, and so the advantages of the one are confounded with the advantages of the other. At the present time, when so much attention is devoted in secondary and technical schools to *matter* rather than to *manner*, when the aim apparently is to turn out scientific encylopaedias rather than fairly well-informed people with cultivated manners, the following opinion expressed by Sir Andrew Noble should be taken to heart by every engineering student: "Speaking as an employer of labour, I should say that we find a pleasant speech and manner, tact in dealing with others, and some power of organisation of the utmost value; and it is precisely those qualities which a boy acquires, or ought to acquire, in his *later* years at a public school. Without such qualities even the highest scientific attainments will never make a captain of industry, and in selecting candidates for appointments the man of business distinctly prefers a youth who has had the benefit of some years at a good school."

From *Nature* 12 October 1899.

50 YEARS AGO

In a fascinating article which appeared in *Nature* of February 6, under the title "Stellar Evolution and the Expanding Universe", Mr. F. Hoyle has brought forward convincing arguments for the permanent creation of matter in space. Many physicists will find it difficult to accept this hypothesis. For if there is any law which has withstood all changes and revolutions in physics, it is the law of conservation of energy, which according to Einstein's formula $E = mc^2$ is equivalent to the conservation of mass. The same strange conclusion has, during recent years, been formulated by Prof. Pascual Jordan, but with an important modification, whereby the conservation law is not violated. This is achieved by taking account of the loss of gravitational energy connected with the creation of particles. As Jordan's papers do not seem to be known to many English-speaking physicists, I have asked him to write a short report of his work, and the following article is a translation of his article made by my collaborator, Dr. H. S. Green.

MAX BORN

From *Nature* 15 October 1949.

One might think that if the end result is the same, with ecosystem properties being measured against a gradient in biodiversity, nothing new should emerge from this line of investigation. Sankaran and McNaughton[5] found, however, that two measures of resistance stability — stability of species composition and stability of species turnover — showed significant and opposite associations with diversity across, but not within, community types (see their Fig. 1 on page 691). These results show that variation in diversity owing to extrinsic determinants may dominate the relationship between biodiversity and ecosystem properties, whereas variation in diversity within communities may play a substantially smaller or different role than current research might lead us to believe. The authors outline several cautionary notes concerning the importance of distinguishing between the various sources of variation in diversity that emerge from this study.

Although Sankaran and McNaughton's study is experimental, it is not, as the authors acknowledge, free from the difficulties associated with studies of natural gradients in diversity. There remains the nagging concern that neither factor measured (plant diversity or proneness to disturbance) is actually responsible for the patterns observed. Multiple regression analyses support the authors' claims, but these statistical methods merely apportion response variance to measured factors, and can neither identify causation nor rule out the possibility that some covarying but unmeasured factor is the responsible agent. This inability to identify causation or mechanism is the main reason that experimental ecologists avoid studying natural gradients in diversity[9]. For the authors to get around these problems, they would have to repeat this enormous experiment, manipulating within-community diversity by adding or removing species in replicate plots, and manipulating grass cover to change proneness to disturbance.

Pursuing such a full factorial experiment would quadruple the size of the study, but would probably not change its message. Sankaran and McNaughton[5] warn us that the effects of extrinsic determinants on large-scale patterns in diversity and the factors, such as local extirpation, that affect fine-scale variation in diversity, are quite different from one another. Understanding the ecological significance of the Earth's extraordinary diversity will require studying both sources of variation. After all, extrinsic determinants, such as atmospheric carbon dioxide, nitrogen deposition and global climate, are themselves changing, much as the local extirpation of species is on the rise. Predicting the ecosystem consequences of biodiversity loss is going to require some branching out from the kinds of experiment that currently dominate research in this area. ■

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Astronomy

Super photon counters

John C. Mather

The perfect photon detector would measure the arrival time, the energy, the polarization and the position of every arriving quantum of light, but that is easier said than done. Two groups have now succeeded in measuring everything but the polarization emitted by the Crab nebula pulsar, as reported in *The Astrophysical Journal* by Romani *et al.*[1] and in *Astronomy and Astrophysics* by Perryman *et al.*[2]. Both groups use superconducting detectors to achieve the necessary speed and sensitivity. Making better detectors is far cheaper than building bigger telescopes and for many astronomers having access to the latest electronic detector is the key to progress.

Three years ago, Peacock *et al.* reported[3,4] that they had detected single optical photons with a superconducting tunnel junction (STJ). A tunnel junction consists of two conductors separated by a tiny gap of insulating material or even a vacuum. If the gap is thin enough, electrons can tunnel across anyway, and if the conductors are superconductors, the junction displays very useful quantum-mechanical properties and electrical nonlinearities. An arriving photon breaks apart the pairs of electrons responsible for the superconducting state, which can then be collected. The main advantages of STJs is that they operate at high speed at very low temperatures, dissipate very little power and are very small.

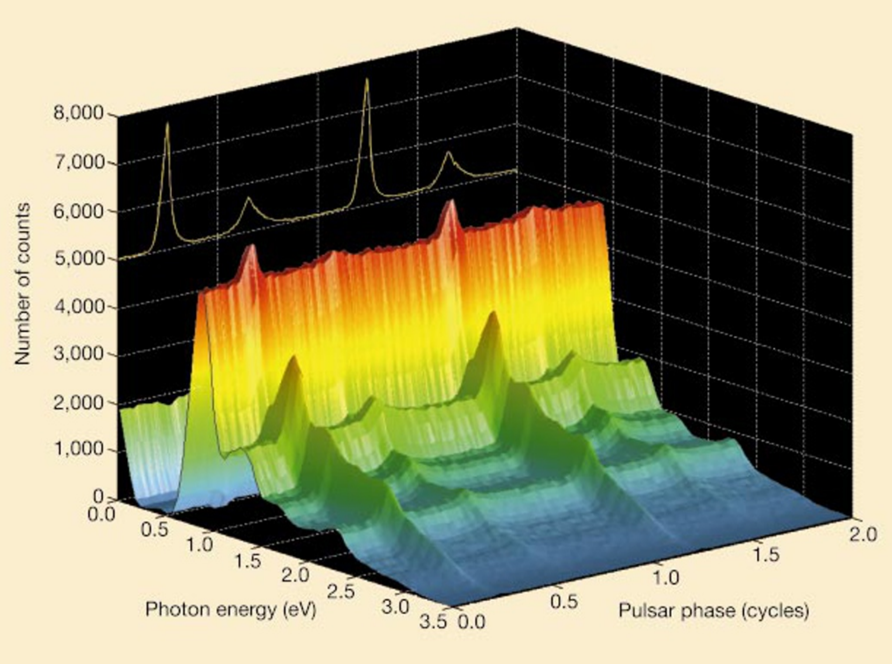

Figure 1 How to catch photons from a spinning pulsar. Time-resolved spectrum of the Crab nebula pulsar recorded by Romani *et al.*[1] using a superconducting microcalorimeter. An arriving photon heats the electrons in the superconductor, which is cooled just below its superconducting transition, thereby producing measurable changes in the superconducting current. (Reproduced from ref. 9.)

Optical detectors containing STJs, such as those reported by Peacock *et al.*, were proposed for use on the Hubble Space Telescope and developed by a group at the European Space Agency (ESA) (the proposed instrument was not in fact selected for the Hubble Space Telescope, but the STJs are still promising for future space missions). Now, Perryman *et al.*[2] have announced the ESA group's first astronomical observation with a 6 × 6 STJ detector array mounted on the William Herschel Telescope at La Palma in the Canary Islands. Considering that each one of the 36 detector elements requires an amplifier and a pulse-height analyser, this was no small feat. They chose the pulsar at the centre of the Crab nebula as their first target. The Crab pulsar spins 30 times a second and is one of the few pulsars that is known to emit optical pulses. Such a rapidly spinning source requires an optical detector with microsecond time resolution to distinguish pulses only 33.5 ms apart. Perryman *et al.* recorded a light curve for the pulsar over the wavelength range 310–610 nm, based on data acquired over a ten-minute interval, with an arrival-time accuracy of 5 μs.

Similar results can be obtained using a cryogenic superconducting microcalorimeter[5], which measures the heat produced by incident photons. Romani *et al.*[1] have measured light curves for the Crab pulsar from near-infrared to near-ultraviolet using a microcalorimeter based on a transition-edge superconducting (TES) sensor (Fig. 1). This sensor consists of tiny 18-μm squares of 40-nm-thick tungsten, similar in size to the individual pixels in semiconductor charge-coupled device (CCD) arrays. The device is cooled to just below the 80 mK superconducting transition of the detector elements, and a voltage is applied to the superconductor so that a current flows. The electrical resistance of the superconductor is still not quite zero, so the current will heat it up a little, quickly reaching a stable equilibrium because the hotter the electrons, the less current can flow. Now, when a photon hits the tungsten and is absorbed by an electron, the temperature of the tungsten–electron system rises a tiny amount, less current flows through the superconductor, and the change can be measured. These TES detectors are very sensitive, partly because very small current changes can be measured using a superconducting amplifier known as a SQUID (superconducting quantum interference device).

Now that superconducting detectors have been shown to work, what next? The ability to measure single photons could be extended to much longer wavelengths. The TES microcalorimeters have an energy resolution of 0.15 eV and are able to detect individual photons with wavelengths up to 4 μm before running into false alarms from electronic noise. To get much better resolution the detector would have to be much smaller or colder, both of which are possible. Small microcalorimeters could be coupled to superconducting 'bow-tie' antennas, enabling the detection of wavelengths longer than the size of the thermometer. For even longer wavelengths, single-photon counting may not be necessary, as the sky is bright with emissions from interplanetary and interstellar dust. In this case, detector sensitivity need only be better than fluctuations from random photons, a performance that is nearly feasible with today's detectors. At the other end of the spectrum the challenge is to detect extremely short wavelengths. X-ray detectors using semiconductor thermistors have already been built for rockets and satellites, and more sensitive versions using TES or STJ technology may fly on NASA's Constellation-X or ESA's XEUS missions[6].

The STJ detector may also be pushed further. The invention of the radio frequency single electron transistor (RF-SET) by Schoelkopf *et al.*[7] opens the door to counting single low-energy photons. Schoelkopf and colleagues' amplifier uses two STJs in series to sense the voltage on a gate capacitor. It is similar to the SQUID amplifier, which uses two STJs in parallel to measure the current in an input inductor. Both the RF-SET and SQUID are quantum-mechanical amplifiers with supreme sensitivity. Work is already underway at Yale University and NASA's Goddard Space Flight Center to test these devices for measuring currents in STJ detectors for far-infrared wavelengths of 100 μm or longer. Another collaboration is building a 200-pixel camera using STJs for the Palomar Observatory at Caltech.

Building the circuitry to operate large arrays of superconducting detectors will require a new level of engineering. CCD detector arrays are already commonplace in digital cameras and digital video recorders, and infrared detector arrays using silicon, germanium and various alloys have also been built. The infrared devices usually have a separate amplifier for each pixel, as well as transistors to apply voltage and reset the accumulated charges. Nothing like this has yet been done for superconducting electronics, but enough principles are known for there to be high hopes. The challenge is to harness new technologies — such as the high-speed SQUID multiplexer[8], in which multiple signals can be simultaneously transmitted — to instrument detector arrays. With broadband detection from every pixel in such an instrument, the potential benefits to astronomy are huge. ■

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