the binary system containing the spun-up pulsar. This encounter eventually left the pulsar in a deformed orbit either with the new star or with the star originally responsible for the spin-up.

This could certainly account for both the eccentricity and misalignment of the pulsar spin and orbital angular momenta. Such collisions are probably quite rare even in dense clusters such as 47 Tucanae; calculations suggest there would be only one collision in the lifetime of the cluster (10^{10} yr). In this case it must have happened fairly recently, within the past 10^7 yr or so, otherwise gravitational radiation would have reduced the eccentricity below the presently observed value. Moreover, within about 10^6 yr, gravitational radiation will cause the system to lose energy and the pulsar and companion to coalesce. So the system as we see it now has a very short lifetime compared with the probable lifetime of the pulsar, which could be a hundred times greater. Again, we are seeing the system in a special situation, very near the end of its life.

The statistical implication of this is that there are a great many similar systems. Several authors[3-5] are concerned that the large number of millisecond pulsars is something of an embarrassment to the spin-up theory, as there do not seem to be enough low-mass X-ray binaries (LMXBs) to give a sufficient rate of production of millisecond pulsars. Ables and co-workers' interpretation of the discovery clearly exacerbates the problem[6]. The production rate is determined by the long lifetime ascribed to the LMXB accretion phase. It is suggested[6] that the problem may be resolved if the length of this LMXB phase were curtailed within about 10^7 yr by a mechanism proposed by Ruderman *et al.*[7], in which radiation pressure from the spun-up pulsar may quench the accretion process.

Because of the three rather awkward implications presented by the interpretation of Ables *et al.*, it is worth considering other possibilities not entertained by them. The first is that the very small mass-function should be taken at face value and that a $1.4\text{-}M_\odot$ neutron star is in orbit with a very light body ($4\times10^{-3} M_\odot$) and with a reasonable inclination of the plane of the orbit to the sky. This Jupiter-like mass would be orbiting the neutron star at a radius of perhaps 100,000 km. This system would be rather like that in which PSR1957+20 has nearly ablated its companion by radiation. It may be significant that the three pulsars with periods shorter than PSR0021–72A are either solitary, presumably having already evaporated their companions, or are in the process of becoming so. The observed advance of periastron in this case would be due to classical effects resulting from the unknown, extended nature of the companion. The apparent finite eccentricity of the orbit is the main unexplained aspect of this interpretation, although it has been suggested[7] that this could arise during the ablation process.

More speculatively, perhaps the 2-ms phase modulation can be explained in some other way: for example, the rotation axis of a distorted neutron star could freely precess; or an exchange of angular momentum between the crust and solid core of the neutron star could take place.

In the absence of any such detailed theory, one of the two binary interpretations would seem to be the most satisfactory. That of Ables *et al.* indicates a most exciting astrophysical laboratory with observable general relativistic effects that are an order of magnitude greater than those seen in the Hulse–Taylor system, which contains PSR1913+16. However, it seems unwise to ignore the sheer improbability of this configuration, and a more likely, if less attractive, classical solution should be sought. □

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EVOLUTION

Pruning the tree of life

Michael J. Benton

THE enormous diversity of life is the result of many evolutionary radiations over billions of years. Key questions about the overall diversification of life and especially individual adaptive radiations were tackled at a recent meeting*.

The best-known example of radiation, that of the placental mammals after the extinction of the dinosaurs 66 million years ago, shows many typical features which can be divided into three stages: rapid initial proliferation of adaptive types, as the mammals radiated to fill the ecological space just vacated by the dinosaurs; early extinctions of several lineages as the ecological space became filled and species competed with each other; and stabilization of the group and evolutionary fine tuning with no further originations of major lines. The first two stages, giving rise to the approximately 20 orders of modern placental mammals, took about 10 million years.

Adaptive radiations of this sort have generally been explained in the past by one of two broad models — the opportunistic model and the key-adaptation model — or a combination of both (S.M. Stanley, Johns Hopkins University). Some interpret the radiation of placental mammals as pure opportunism — the radiating group might just as well have been the frogs, lizards or snails, all of which were present, but the mammals got going first. Others stress a 'key adaptation' that made it inevitable that the mammals would actually succeed: efficient teeth or limbs, intelligence, warm-bloodedness or parental care could be such adaptations.

The key-adaptation model, cited to explain evolutionary models in many groups, seems particularly convincing when applied to marine molluscs. P.W. Skelton (Open University) argued that the present diversity of bivalves (cockles, mussels, oysters and their kin) can be traced to the evolution of key adaptations to avoid predation. The appearance of adaptations such as the ability to burrow

* *Major evolutionary radiations*, Durham, 6–8 September, 1989. To be published in 1990 as *Systematics Association Special Volume* 38 (Oxford University Press).

100 years ago

A REMINDER that today is the twentieth anniversary of the first issue of *Nature*, will not, perhaps, be without interest to our readers. A formal history of science for the last twenty years would be a formidable task, but it is already possible to discern what will probably appear to posterity to be the most salient characterstics of the last two decades.

In the biological sciences, progress has consisted chiefly in the firm establishment of the Darwinian doctrine, and the application of it and its subordinate conceptions in a variety of fields of investigation.

The nucleus of the protoplasmic cell — which twenty years ago had fallen from the high position of importance accorded to it by Schwann — has, through the researches of Bütschli, Flemming, and Van Beneden, been reinstated, and is now shown to be the seat of all-important activities in connection with cell-division and the fertilization of the egg.

The British Government has shown a decided inclination to extend subsidies to scientific research: the grant to the Royal Society has been increased from £1000 to £4000 a year; and subsidies have been voted to the Marine Laboratory, the Committee on Solar Physics and the University Colleges.

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into the sea bed, the ability to become cemented to hard substrates, or the ability to escape by swimming (scallops), was generally followed by a rapid proliferation of the group.

J.D. Taylor (British Museum (Natural History)) similarly showed how the success of neogastropods (20,000 species) can be traced back to their radiation in the Cretaceous, some 100 million years ago, when they began to evolve a fiendish array of predatory adaptations. Some can bore holes into hard-bodied prey through which they suck their victims' flesh; others can catch prey with a long snake-like proboscis; some swallow their prey whole by powerful suction; others have complex venom glands and even modified hollow 'teeth' that are shot into their prey like hypodermic poison darts. Unlike many of these predatory adaptations, hole-boring predation can be tracked back in the fossil record. Fossil shells with holes that were bored by particular gastropods became more common during the Cretaceous. This occurred in parallel with the radiation of the hole-borers, thus providing cogent evidence for the radiation and effectiveness of at least this adaptation.

Other contributors found less evidence that key adaptations could explain the radiations of their chosen groups of organisms. M.B. Hart (Plymouth Polytechnic) emphasized the role of repeated extinction events and opportunistic radiation in the fossil record of planktonic foraminifera. After an extinction event, the survivors, which seem to have been mainly surface-living forms, radiated to occupy deeper positions in the water column. Extinctions over the past 250 million years have also triggered radiations of echinoderms (M.J. Simms, Trinity College, Dublin) and terrestrial tetrapods (A.R. Milner, Birkbeck College, London; my own work). By contrast, evolutionary radiations of colonial animals involved major structural changes in the colony form that are best explained by heterochronic change. Evidence was presented for the corals (B.R. Rosen, British Museum and J.M. Pandolfi, Australian Institute of Marine Science), bryozoans (P.D. Taylor, British Museum; G.P. Larwood, University of Durham), and for the extinct, largely planktonic colonial graptolites (C.E. Mitchell, State University of New York, Buffalo).

Several contributors addressed the so-called null or neutral model, which states that species may diversify by chance alone, and not for any particular biological or physical reason. Although the issue was considered in biological and statistical terms, the consensus was very much against this model.

Radiations at higher levels than the individual adaptive radiation may also yield general patterns and models of evolutionary interest. The diversification of the tetrapods, for example, is largely the result of the conquest of new 'adaptive space' and the subdivision of niches, or increasing specialization of species and families. There does not seem to have been any in-built progressive 'tendency' in their evolution. D. Jablonski (University of Chicago) and D.J. Bottjer (University of Southern California, Los Angeles) note that marine invertebrates have repeatedly shown environmental patterns of radiation. Most of the main groups arose in shallow waters and then migrated over tens of millions of years into deeper seas. New groups then replaced them in the near-shore waters. This remarkable 'conveyor belt' is unexpected and may have parallels elsewhere. Skelton and co-authors find evidence that most of the main bivalve groups arose at high latitudes and subsequently migrated towards equatorial seas; Jablonski and Bottjer, however, find that most other marine groups arose at low latitudes and migrated north and south. Similarly, P.R. Crane and S. Lidgard (Field Museum of Natural History, Chicago) report an equatorial origin for flowering plants, with a subsequent migration to temperate latitudes.

A potential problem with studies of evolutionary radiations is the incompleteness of the fossil record. This may be a serious problem in studies of the well known Early Cambrian radiation, some 570 million years ago, when hard parts first appeared in the fossil record, and molluscs, arthropods, echinoderms and others apparently radiated very rapidly. It is not known whether this seemingly rapid radiation is preceded by a significant gap in the fossil record (S. Conway Morris, University of Cambridge). Most parts of the fossil record are, however, complete enough for valid macroevolutionary studies, with many hundreds of fossil deposits showing exceptional preservation. These have provided information on soft-bodied organisms, as well as hard-bodied organisms with delicate structures. Together, they enable palaeontologists to interpret with confidence those intervening parts of the fossil record showing poorer preservation.

The other key problem in studying radiations is establishing the precise geometry of such patterns, the shape of the tree of the history of life. Most of the 21 studies presented at the meeting were based on new cladistic analyses, a rigorous technique for assessing patterns of lineage splitting. Cladistic techniques are becoming the norm for macroevolutionary studies and promise increasing success for the palaeobiological study of evolutionary radiations. □

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DAEDALUS

Floating on air

THE hovercraft supports itself on a cushion of pressurized air, maintained between its underside and the ground. But lacking sides, the cushion leaks absurdly freely. Air has to be pumped down into it at an enormous rate to sustain the pressure. Daedalus is now designing a novel leak-proof hovercraft. It pumps air inwards into its cushion from all round its periphery, exactly opposing the outward leakage.

The basic principle is that oxygen, and therefore air, is paramagnetic. So it can be entrained and pumped by a moving magnetic field. The periphery of the DREADCO hovercraft is studded with linear magnetic motors, whose field pattern runs radially inwards at high speed. These motors pump air in under the craft until sufficient pressure has built up to oppose further inward flow. Acting on weakly paramagnetic air, even the most powerful linear motors can only pressurize the central cushion by a tiny fraction of an atmosphere — but over the whole bottom area of the craft this should be enough to float several tons.

This novel vehicle has two great advantages. First, once established, its supporting air cushion will be quite static. With no fans or air draughts, the magnetic hovercraft will be utterly silent. It will float above the ground as enigmatically as a flying saucer. Second, the magnetic pumps merely serve to maintain a static pressure-gradient across the peripheral air of the cushion. They do no work of compression and with luck will consume very little energy. The craft should be very efficient.

As with all hovercraft, propulsion poses a problem. Bleeding off cushion air for jet propulsion would sabotage its lift; biasing the linear motors to drive the craft along a metallic track would tie it down like a train to a railway. Daedalus hopes to build a novel jet engine on the same principle as his magnetic air-pump: a long tubular linear motor, sucking air in at one end and blowing it out the other. Even modest thrust from such a quiet and simple engine should give his frictionless vehicle a useful turn of speed. And two parallel engines could be biased against each other to steer it.

The magnetic hovercraft should be very popular with environmentalists and nature lovers. Alone among heavier-than-air vehicles, it will produce no downwash. It will travel quietly over crops and meadows and swamps and tidelands, without alarming the wild life or flattening the vegetation. In towns, however, its stray field may be something of a liability. It will be greatly perturbed by iron manhole covers and tram tracks, and may ingest beer cans and scrap metal. Daedalus plans to give the craft magnetic sensors which momentarily switch off any linear motor that encounters such embarrassing challenges. David Jones