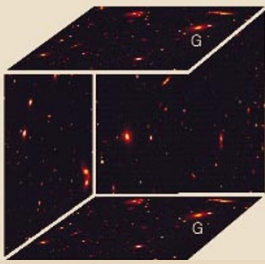


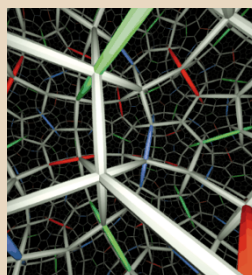
Small 'open' spaces

How can a space be finite and yet have no edges? The simplest way to achieve it is to take a cube, and identify each face with that on the opposite side. In the diagram below, galaxy G is on both the top and bottom of the cube – this is called a periodic boundary condition, and makes the space multiply connected. Travelling in any straight line, you would cross the cube repeatedly. This cube is known as



the fundamental domain of the space. Its boundaries are arbitrary: there is no physical threshold to cross, and, looking into the distance, you would see patterns and objects repeating themselves – including the back of your own head. The space thus defined is called a three-torus, T^3 , and is locally identical to ordinary euclidean space, R^3 .

Similarly, there are finite spaces with negative curvature, or 'compact three-hyperboloids'. Examples can be constructed by identifying opposite faces of a suitable polyhedron. For example, a dodecahedron with opposite faces fitted



together after rotating by 108° spans a three-hyperboloid space, known as the Seifert-Weber space (top right¹²). There are infinitely many types of three-hyperboloid^{13,14}. Their volumes are related to their curvature, unlike the torus in flat space whose volume is arbitrary. The volume is at least larger than $0.00082 r^3$, where r is the radius of curvature. **M.F.**

wave-background fluctuations are dominated by the gravitational potential at low redshifts (in the nearby Universe), and are hardly anything to do with physics at the last scattering sphere. So if the Universe has less than critical density, the COBE observation does not give a strong constraint on the size of the Universe.

Instead, the size of our space should be betrayed by identical circles of fluctuation on the microwave sky, where the horizon-size sphere of last scattering crosses the boundary of the fundamental domain centred on Earth (see box). This is conceived best by considering the intersection of a sphere with a slightly smaller cube. The intersection on each face of the cube forms a circle, and because of the periodic boundary condition, a circle on the upper face, say, must be identical to that on the lower face. The number, the relative angle and the size of identical circles will tell us what topology our three-hyperboloid has. This is no distant dream. Two satellites in the planning stages will be able to make such measurements: NASA's microwave-background mission MAP, planned for launch in the year 2000; and ESA's PLANCK, scheduled for 2006.

Whether the curvature of the Universe is negative or flat is still a matter of debate (no evidence supports positive). But the majority of recent observations — of the expansion speed versus the age of the Universe, of the evolution of galaxy clustering, of the brightness of distant supernovae — are in favour

of a low-density Universe. If empty space has no inherent energy (another matter of debate), low density means negative curvature. A precise measurement of the microwave fluctuations on a small angular scale could be definitive, so MAP and PLANCK may be able to answer this part of the question too.

So what is the physical significance of

Systematics

Sequences lead to tree of worms

Claus Nielsen

Nematode worms are found just about everywhere, often in enormous numbers. Parasitic species live in almost all animals and plants, and only arid soils and the open oceans seem to be unsuitable for free-living species. Yet only about 15,000 species have been formally described, and some textbooks treat nematodes as one of the 'minor phyla'. In spite of this, it is now believed that the number of living species should be counted by the million. Classification has been difficult because most of the species are small to microscopic in size, and they lack obvious distinguishing characteristics. But the first attempt at a phylogenetic classification — based on small-subunit ribosomal DNA sequences from 53 species — is presented by Blaxter *et al.* on page 71 of this issue¹. And, according to their findings,

topology? Some theorists speculate that the Universe was created from nothing^{10,11}, as a quantum vacuum fluctuation. That idea requires the Universe to be finite. Another theoretical advantage of a compact three-hyperboloid is efficient chaotic mixing². Any excitation created in this manifold dissipates rapidly: excitation of one mode excites all other modes, and this smears out inhomogeneities that would have existed in the pre-inflationary epoch, solving a problem that faces inflationary cosmologists. In a negative-curvature Universe, inflation takes place only partially and does not produce a Universe as homogeneous as the one we observe, unless we start with a homogeneous initial condition. Chaotic mixing could prepare such an initial state. Perhaps the Universe is so smooth because it is small. \square

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only one of the two classes of nematode that are recognized in the traditional classification is natural, consisting of an ancestral species and all its descendants.

Free-living nematodes are found in terrestrial soils and marine sediments, where they decompose plant and animal material. Parasitic species of nematode infect common crops such as potatoes, soya beans and corn, as well as livestock, including pigs, cattle and chicken. Human parasites include species that cause crippling or fatal diseases such as filariasis (elephantiasis), trichinosis and hookworm disease. Conversely, parasitic species of nematode are increasingly being used in biological control — some species directly attack and destroy the larvae or adults of plant parasitic insects, whereas others transmit bacteria that destroy the parasite (Fig. 1). \blacktriangleright

Most (but not all) nematodes are small and nondescript. For example, *Placentonema gigantissima*, which lives as a parasite in the placenta of sperm whales, grows to a length of 8 m, with a diameter of 2.5 cm. The free-living, marine *Draconema* has elongate adhesive organs on the head and along the tail, and moves like a caterpillar. But the general uniformity of most nematode species has hampered the establishment of a classification that includes both free-living and parasitic species. Two classes have been recognized (the Secernentea and Adenophorea), based on the presence or absence of a caudal sense organ, respectively. But Blaxter *et al.*¹ have concluded from the DNA sequences that the Secernentea is a natural group *within* the Adenophorea. Based on studies of free-living species, a paraphyletic nature for the Adenophorea — that is, a group comprising an ancestor but not all of its descendants — has previously been suggested (for example, by Lorenzen²), but the position of the various parasitic groups has always caused trouble.

One of the most interesting results of the new phylogeny is the discovery that there have been many parallel shifts of feeding strategy within the phylum. The ancestral form was obviously free-living, but the results of Blaxter *et al.* support the idea that parasitism has evolved independently many times. Of the plant parasites, for example, the order Triplonchida comprises only plant parasites, whereas Dorylaimida comprises both omnivores and plant parasites. And the sister orders Aphelenchida and Tylenchida both comprise fungivores, plant parasites — among which the eelworms (Fig. 2) parasitize many important crops, such as potato and sugar beet — and animal parasites.

The animal parasites also belong to several groups that probably evolved independently. Outside the Secernentea, the Tricocephalida comprises mammalian parasites (such as the trichina worm) which do not have an intermediate host. But the Mermithida mainly comprises species that have a juvenile stage in which they infest insects. Within the Secernentea are the Strongylyda



Figure 2 The bad — eelworm (root knot nematode), which forms characteristic nodules on the roots of sugar beet and rice.

and Rhabditoidea (which are probably sister groups), Strongyloididae, Apelenchida and Tylenchida. The Strongylyda comprises vertebrate parasites without an intermediate host (an example is the hook worm). The Rhabditoidea, by contrast, comprises free-living species, such as the favourite experimental model *Caenorhabditis elegans*, and insect parasites. And the Strongyloididae comprises mammalian parasites, many of which infest horses, pigs and cattle.

Blaxter *et al.* also identified a large parasitic group within the Secernentea, comprising three groups of vertebrate parasites (the Ascaridida, Spirurida and Oxyurida) and one group of invertebrate parasites (the Rhigonematida). Of the Ascaridida, some species (for example, *Ascaris* spp.) live in vertebrate intestines. But others, such as species of *Anisakis*, have more complex life cycles, with a crustacean as the first host, a fish as the second host and a fish-eating bird or mammal as the final host. The Spirurida live in vertebrate tissues, and they are transferred by biting or sucking insects. Well-known species include the filaria worm and the whip worm. Of the Oxyurida, the pinworm is a common but harmless human parasite. Finally, the Rhigonematida comprises parasites of terrestrial arthropods.

The establishment of a natural — that is, phylogenetic — classification for the nematodes is an absolute necessity for all aspects of nematode studies, practical as well as theoretical. Moreover, the classification described by Blaxter *et al.* will be an invaluable tool for parasitologists, who search for relationships between parasitic species. They can use this information to look for free-living relatives of important parasites that may be difficult to culture, or for ways in which to combat pests. □

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Daedalus

Fibre couplings

The nail, says Daedalus, is a brilliant and versatile fastener, but with a fundamental contradiction. While being hammered in, it is a strut, loaded in compression. It must be thick enough to resist buckling. Yet once in place it is a tie, loaded in tension, and should be thin and flexible to bear its load efficiently. He is now resolving this contradiction.

An ideal nail, he says, should be driven in by a force applied, not to its head, but to its point. Its shaft would then be drawn in under tension; it could not buckle, and would form a perfect tie. But how to apply a force to the point of a nail? Well, suppose the blow on its head lasted only a microsecond. In this time, the shock would travel only a millimetre or so down the nail. The compressed region would be far too short to buckle. The pulse would travel down the nail, and would force the point into the material being fastened. Any reflected energy would travel safely back up the nail as a tension.

Now only the most rigid materials could have an impact time of a microsecond. A diamond hammer driving a diamond nail would be wonderful engineering but disastrous economics. But in electronics, microseconds are positively leisurely. A piezoelectric transducer could hit a nail thousands of times a second. Quartz is piezoelectric, and quartz fibres have amazing tensile strength. So Daedalus is now inventing the quartz-fibre piezoelectric nail.

His ‘piezonail’ will be a fine, flexible fibre with plated electrodes, and embedded in a plastic reinforcing jacket. You will fit it into a recess in its pulse-generator ‘hammer’, hold it firmly against the object to be nailed, and switch on. The burst of pulses will force it silently and instantly into the material, giving a strong, tensioned, firmly bound tie. In thick or hard materials, the piezonail will not even need a head; friction will hold it firmly enough. Many thin ties are superior to one thick one, so the hammer will also accept a ‘polynail’ containing many parallel piezonails in one jacket.

Construction will be transformed. The global toll of bent nails, bruised thumbs and ringing ears will plummet as the piezonail spreads through engineering, carpentry and DIY bodging. A piezonailed structure will be strong, stable, secure — and somewhat enigmatic. Its myriads of fine fixing fibres will be almost invisible, giving no clue as to what holds it together, or how to get it apart again.

David Jones



Figure 1 The good — *Steinernema bibionis*, a free-swimming parasitic nematode used for biological control of vine weevils.