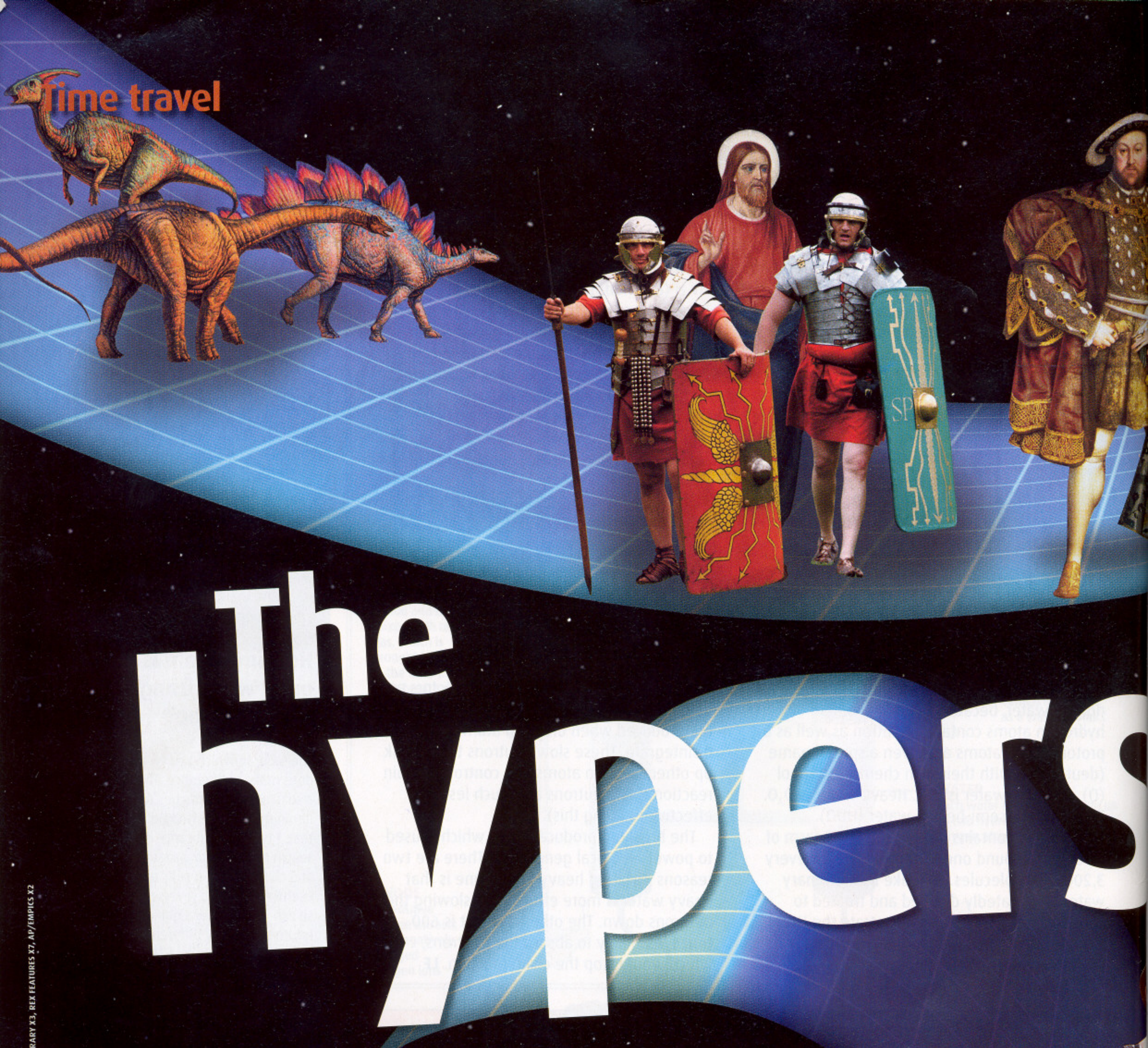


The hypers

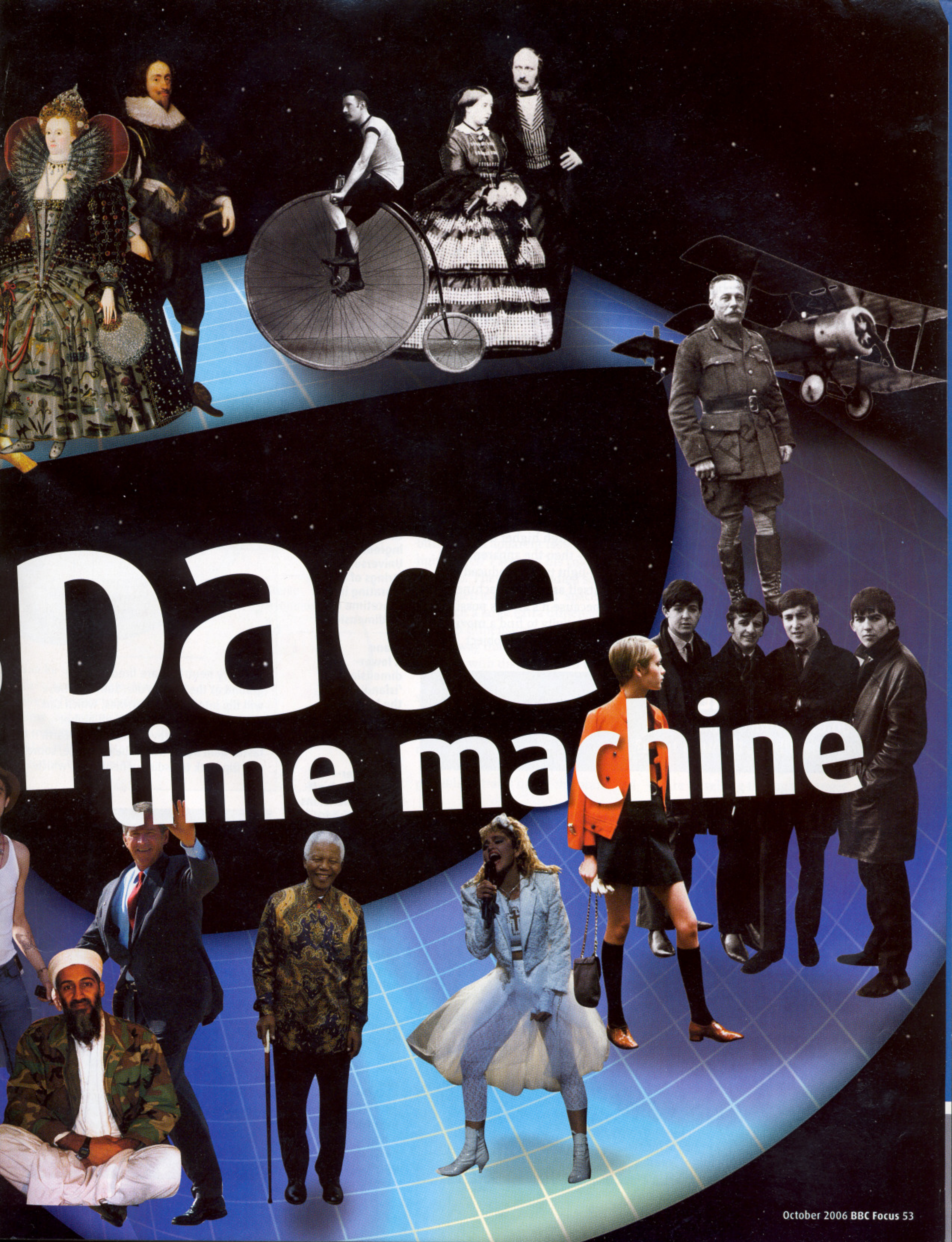
Could extra dimensions of space open up portals to the past? Some scientists think so, and are setting about testing the idea. **Marcus Chown** investigates

ILLUSTRATION BY PAUL WOOTON, SCIENCE PHOTO LIBRARY X3, CORBIS X2, ALAMY X3, BRIDGEMAN ART LIBRARY X3, REX FEATURES X7, AP/EMPICS X2

At a laboratory at the North Pole, a physicist flips a switch. A pencil thin beam of subatomic particles known as neutrinos stabs down through the rock of the Earth. At a laboratory on the equator a spike on a computer screen registers the neutrinos' arrival. The physicists crowding around the computer monitor are stunned. They check and re-check the timing. It cannot be true – but it is. The neutrinos arrived before they set off.

Surely, it is impossible for anything to travel into the past, as these neutrinos have done? You might think so. However, a team of physicists in the US maintains it is easy to envisage scenarios in which particles travel back in time – if, as many believe, we live in a universe of more than four spacetime dimensions.

Heinrich Paes and Sandip Pakvasa of the University of Hawaii, at Manoa, and Thomas Weiler of Vanderbilt University, in Nashville, have been investigating the higher dimensional universe of 'string theory'. According to the theory, the fundamental building blocks of the Universe are not point-like 'particles' but ultra-tiny vibrating 'strings' of mass-energy; the faster the vibration the more massive the particle. Crucially, such vibrating strings can mimic the behaviour of all the known subatomic particles, such as quarks and electrons, only if they vibrate in a spacetime of 10 dimensions ➡



pace time machine

➥ rather than the four we are familiar with. String theorists maintain that the extra space dimensions are either so fantastically tiny that they have so far gone unnoticed or large but 'warped' in such a way that, again, they are hidden from view.

String theory does not contain only one-dimensional strings. There is room for higher dimensional entities within the multidimensional space. This has led to the proposal that our Universe may be a four-dimensional island, or 'brane', adrift in a 10-dimensional space, or 'bulk'.

"If it is," says Paes, "it's easy to imagine shortcuts through the higher dimensional space. And such shortcuts are what make time travel possible."

Say, for instance, our brane-universe is bent back on itself in a large extra dimension – the four-dimensional equivalent of a pancake folded in two. Clearly, it is possible to leave the brane at one point, travel a short distance through the bulk, and re-enter the brane at a point far away from the exit point, forming a shortcut (see graphic below). That works in principle, but the structure of our own Universe is slightly more complicated. Einstein's special theory of relativity – the branch of physics governing the behaviour of fast-moving objects in our Universe – requires an essentially 'flat', or unwarped, space. At least, it does in our vicinity.

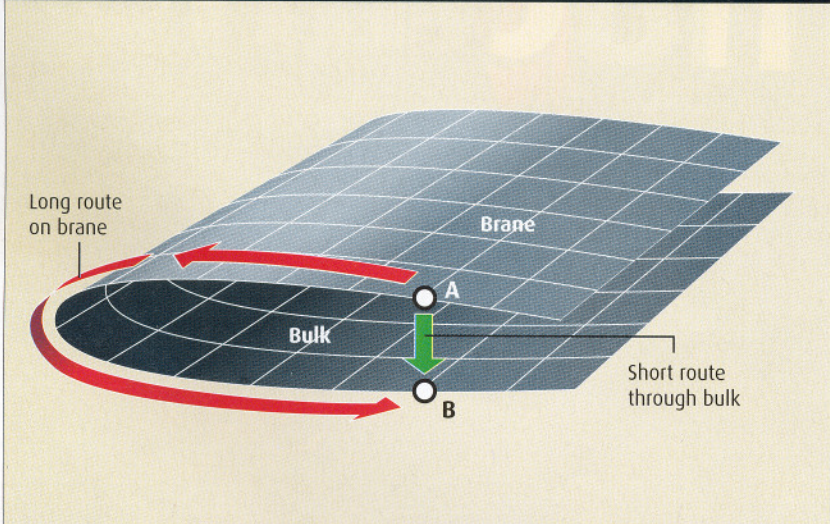
Taking a shortcut

But that turns out to be a good thing. Special relativity says that on the brane nothing can travel faster than the speed of light. But if you can cheat and travel faster than light by other means – in this case, by nipping down a shortcut through higher dimensional hyperspace – then the apparent faster-than-light travel produced can manifest itself as a time machine.

That's because it's always possible in special relativity to find a moving viewpoint from which an object

SPACE AND TIME

How do extra space dimensions let you travel back through time?



Leave the brane at A, take a shortcut through the bulk, and reappear at B, having apparently travelled faster than light. Crucially, you can appear to be moving back in time if B is moving relative to A. To do this with our Universe is much more complicated because the space must be warped in such a way that it doesn't violate Einstein's special theory of relativity. However, this could be possible using so-called 'asymmetrically warped' spacetimes.

ILLUSTRATIONS BY RICHARD PALMER, ROBERT MORSE/NSF

» JARGON BUSTER

Spacetime
Space and time merged into one seamless entity

Dimension
An independent direction in spacetime. The familiar world has three space dimensions (left-right, forward-backward, up-down) and one of time (past-future)

String theory
Theory which postulates that the fundamental ingredients of the Universe are tiny strings of matter vibrating in a spacetime of 10 dimensions

Brane
A lower-dimensional 'island' in the higher dimensional space of string theory

Bulk
The higher-dimensional, off-brane dimensions in string theory

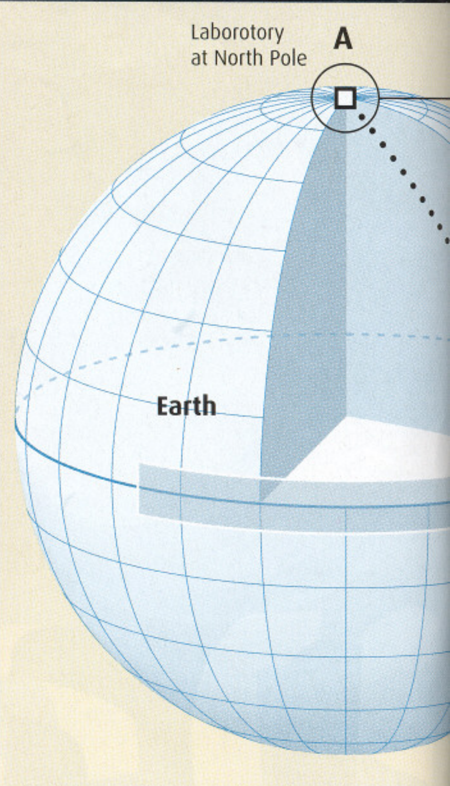
Neutrino
Subatomic particle with a very small mass that travels very close to the speed of light. Neutrinos come in three major types and hardly ever interact with matter

Sterile neutrino
Hypothetical fourth neutrino that interacts even less with its surroundings

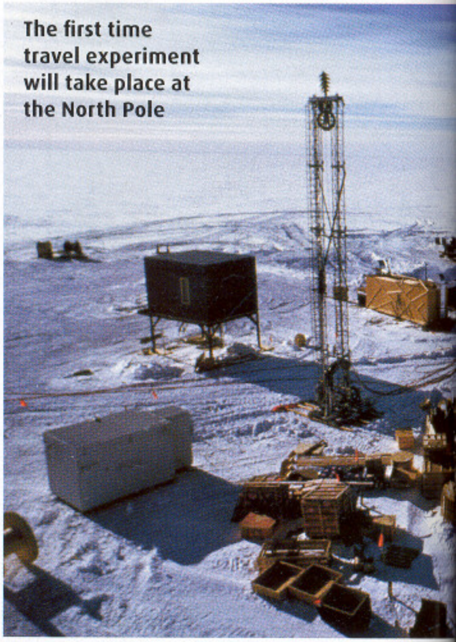
Graviton
Hypothetical 'carrier' of nature's gravitational force

TIME TRAVEL ON TEST

The experiment that could chang

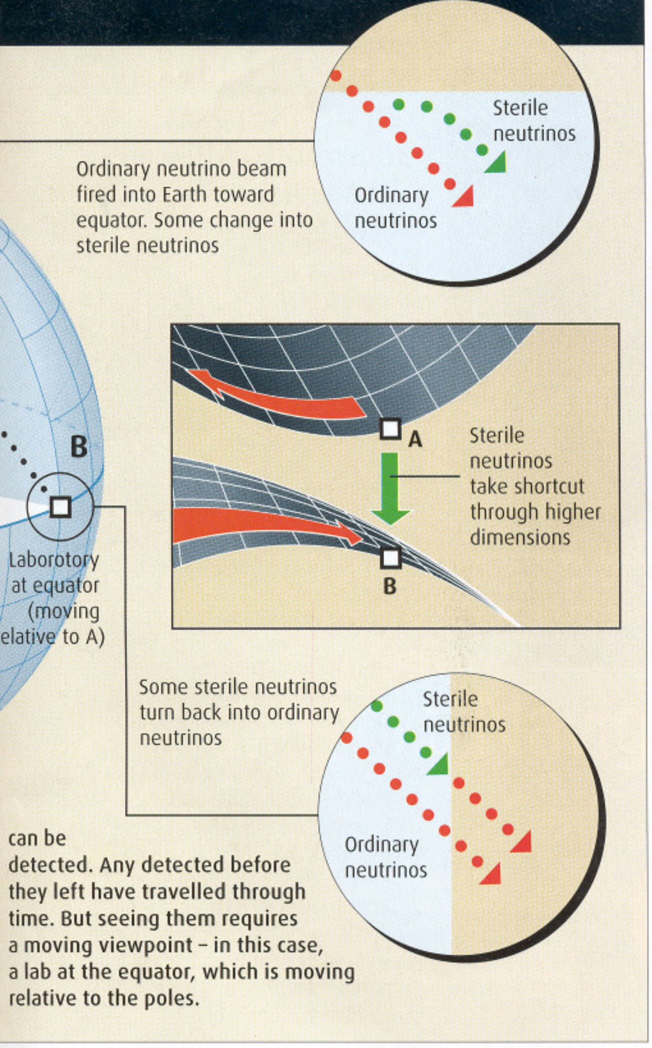


Ordinary neutrinos are fired into the ground at the North Pole. Some of these will flip into sterile neutrinos, which can then take a 'shortcut' through higher dimensions and travel through the Earth faster than light. When they emerge, some will flip back to ordinary neutrinos, which



The first time travel experiment will take place at the North Pole

e world – and the past



can be detected. Any detected before they left have travelled through time. But seeing them requires a moving viewpoint – in this case, a lab at the equator, which is moving relative to the poles.

going faster than light appears to be travelling back in time. For instance, if someone travelling faster than light loosed a bow and arrow and then put the bow down and fired a gun, an observer could always move in such a way that they would see them fire the gun and then shoot the bow and arrow – as if they were travelling backwards through time.

The moving object has to exceed the cosmic speed limit of the speed of light for this to happen. And for a cosmic speed limit to exist, special relativity must hold sway on the brane.

The key question is therefore: are there spacetimes in which special relativity applies on the brane and in which shortcuts through the bulk permit apparent faster-than-light travel? Paes and his colleagues think so. They have studied so-called 'asymmetrically warped' spacetimes in which a large extra dimension – call it a fifth dimension – is warped in such a way that the cosmic speed limit changes with distance from the brane.

"In such a spacetime, we have found shortcuts through the bulk that, to inhabitants of the brane, appear to permit faster-than-light travel. It's the recipe for a time machine," says Paes.

Of course, this all assumes that it's possible to travel out of the brane and into the bulk to take advantage of these higher-dimensional shortcuts. Paes believes this is also possible. He says that some sub-atomic particles, such as the 'graviton' (theorised to be the carrier of the gravitational force) and the 'sterile neutrino' (a hypothetical fourth neutrino – see 'Jargon buster', opposite) are free to leave the brane and travel into the bulk. "Gravitons and sterile neutrinos, with their ability to take shortcuts through the bulk, are potential time travellers," say Paes. "If we can manipulate them, we can study time travel experimentally."

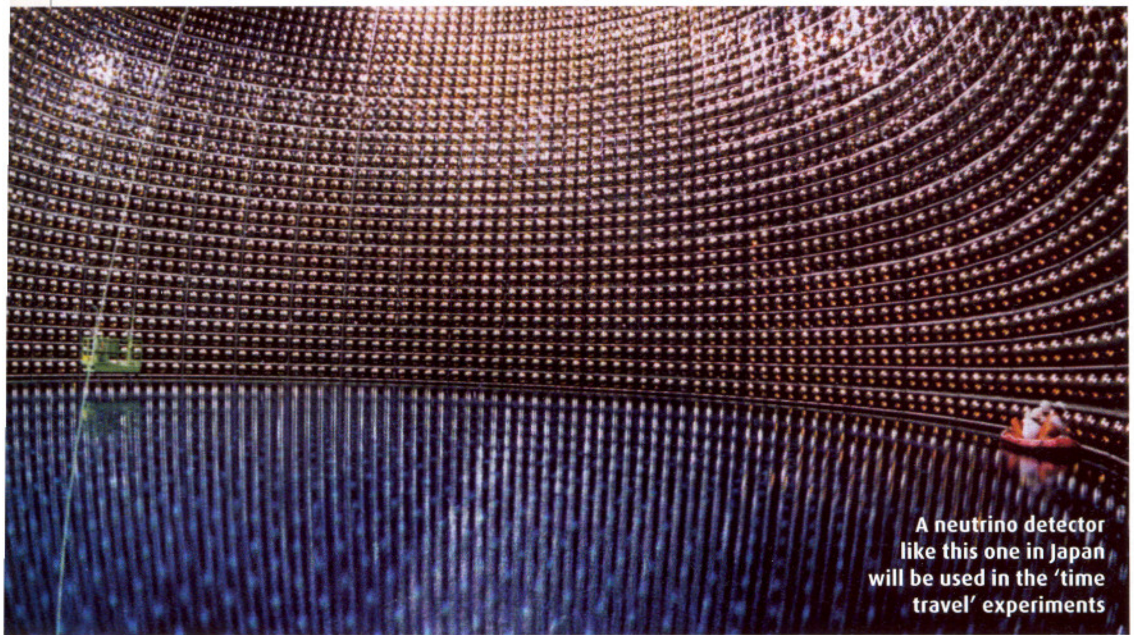
Faster than light

So far, no one has ever detected a graviton or a sterile neutrino and both particles are expected to be ultra-elusive. Sterile neutrinos, for instance, make ordinary neutrinos – which themselves can pass through the Earth without being stopped – appear positively sociable.

Nevertheless, Paes and his colleagues point out that, if sterile neutrinos exist, ordinary neutrinos will very occasionally change, or 'oscillate', into their sterile form and back again. And this transformation will be enhanced whenever the density of the matter that the neutrinos are travelling through changes. ➥

OTHER TIME MACHINES – AND WHY THEY DON'T WORK

WHAT?	HOW?	WHY NOT?
Gödel universe	Globally rotating spacetime. Conjectured by mathematician Kurt Gödel	We don't live in such a rotating universe!
Black hole interior	Spacetime inside the 'event horizon' – or point of no return – for matter falling into a spinning black hole	Inaccessible to us unless we are prepared to go inside a black hole and never come out again
Superdense rotating cylinder	Spacetime around an infinitely long, rapidly rotating, massive cylinder. Hypothesised by cosmologist Frank Tipler	Impossible to construct and, besides, it requires faster-than-light travel *within* our Universe, which appears impossible
Wormhole	Shortcut through spacetime connecting a normal region of space with one where time runs more slowly – for instance, near a black hole. If clocks start off at Monday in both regions, when it's Friday in one region it's still Tuesday in the other. By going down the wormhole, someone can go from Friday back to Tuesday	Wormhole mouths are unstable and rapidly snap shut unless propped open by so-called 'exotic matter' that has repulsive gravity. Nobody knows whether this substance exists or whether it is stable



A neutrino detector like this one in Japan will be used in the 'time travel' experiments

KAMIOKA OBSERVATORY/ICRR/UNIVERSITY OF TOKYO

➡ The team believe this could form the basis of the first ever experiment to test time travel (see 'Time Travel On Test', p54-55). Paes admits that such an experiment is beyond the capabilities of current technology. But he says it is realistic within the next 50 years.

Of course, getting a positive result from the experiment hinges on two things – the existence of sterile neutrinos and that we live in an asymmetrically warped spacetime – both of which many physicists assign quite long odds to.

Warped theory

Paes points out that the brane scenario is far more plausible than others that have been suggested for time travel (see table on p55). However, he confesses that his idea requires exotic matter – hypothetical stuff with repulsive gravity – to warp spacetime in the right way. Exotic matter is required by other time machines, such as wormholes. "The advantage of our scenario is that there is no exotic matter in the brane – it is hidden away in the higher-dimensional bulk."

Not everyone is convinced. Stanley Deser of Brandeis University, Massachusetts, says hiding exotic matter away isn't much improvement on a scenario where it's not hidden. "It's only a matter of degree," he says.

John Cramer of the University of Washington, in Seattle, is also cautious. "The scheme requires asymmetrically warped brane universes – and our Universe may not be one of these," he says. "But it's a fascinating proposal."

It could be very fascinating if, in 2056, someone carries out Paes's experiment and detects a pulse of neutrinos before the pulse set off. This would open up a can of worms over the paradoxes that time travel throws up. For example, a signal might go back in time and prevent itself being created. This is the 'grandfather paradox' in which a person goes back in time and shoots dead their grandfather before their mother was conceived. Then there's the possibility of a signal going back in time and creating itself. This is the 'bootstrap paradox' in which a person can be his own father or mother, or both – as in the story *All you zombies* by Robert Heinlein (see http://tinyurl.com/mnfb).

Even if time travel is possible, it may be accessible only to very special particles like sterile neutrinos. But what if it's not? What time period would you visit if you could surf hyperspace into the past? F

Marcus Chown is the author of* The Quantum Zoo *(Joseph Henry Press, 2006)

» FIND OUT MORE

Closed timelike curves in asymmetrically warped brane universes
by Heinrich Paes, Sandip Pakvasa and Thomas Weiler, http://xxx.lanl.gov/abs gr-qc/0603045

Time Travel in Einstein's Universe
by Richard Gott (Phoenix Press, 2002)

The Universe Next Door
by Marcus Chown (Headline, 2003)

The River of Tim
by Igor Novikov

ASK THE EXPERT

Dr Heinrich Paes University of Hawaii at Manoa

Physicists are terrified of time travel. Why?
Because it could potentially upset one of our most cherished ideas – that an effect always follows a cause. Without 'causality', chaos would ensue and all kinds paradoxical events might be possible, such as the famous grandfather paradox.

How might the grandfather paradox be avoided?
One way has been proposed by David Deutsch of the University of Oxford. According to Deutsch, if there are parallel realities, stacked like the pages of an infinite book, then, if you go back in time and shoot your grandfather dead before your mother was born, you change a version of your grandfather in a parallel reality, not the one who lived in your reality.

What if there aren't parallel realities?
Then, possibly, something else prevents time travel. Stephen Hawking has proposed the 'chronology protection conjecture'. Basically, it says that some as-yet-undiscovered physics will always come to the rescue by forbidding time travel.

So how has your work added to the time travel debate and moved the subject on?
First, we've come up with what we think is the most plausible spacetime scenario for time travel. And, secondly, we have proposed an experiment to test whether time travel is possible. Even if it isn't possible, by manipulating particles like sterile neutrinos we can try and find out what physics intervenes to prevent it.