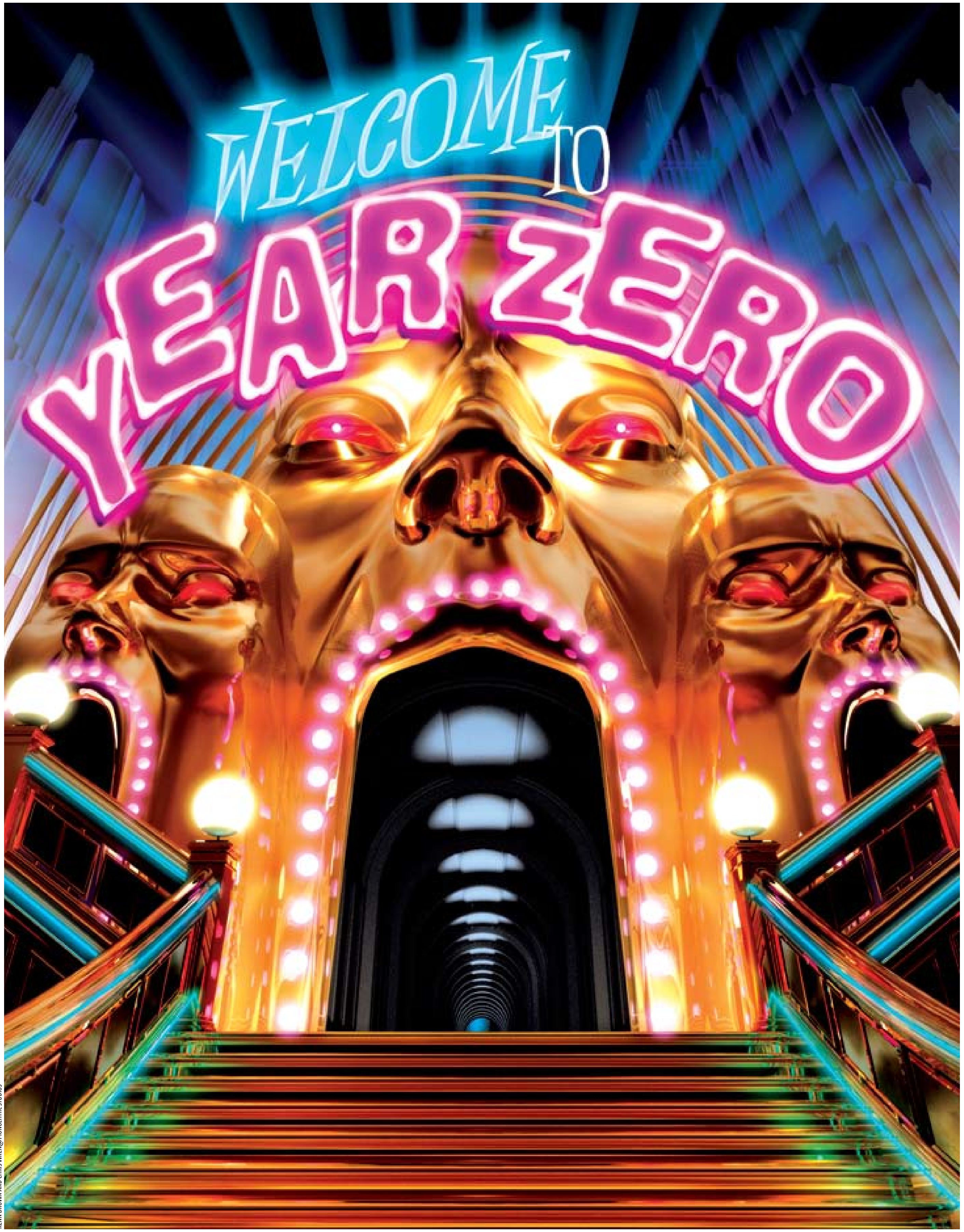

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If time travel becomes possible, 2008 may be the destination of choice. **Michael Brooks** gets ready to receive visitors from the future

AS YOU may have heard, this will be the year. The Large Hadron Collider – the most powerful atom-smasher ever built – will be switched on, and particle physics will hit pay-dirt. Yet if a pair of Russian mathematicians are right, any advances in this area could be overshadowed by a truly extraordinary event. According to Irina Aref'eva and Igor Volovich, the LHC might just turn out to be the world's first time machine.

It is a highly speculative claim, that's for sure. But if Aref'eva and Volovich are correct, the LHC's debut at CERN, the European particle physics centre near Geneva in Switzerland, could provide a landmark in history. That's because travelling into the past is only possible – if it is possible at all – as far back as the creation of the first time machine, and that means 2008 could become Year Zero: a must-see for the discerning time traveller.

Aref'eva and Volovich are sensible and well-respected mathematicians, based at the Steklov Mathematical Institute in Moscow, so they are not actually suggesting that visitors from the future are imminent. What they are saying is that since causality – the idea that effect must follow cause – is one of the most fundamental principles of physics, the notion that it might be tested at the LHC is worth pushing as far as possible. Their work has yet to be recognised by a peer-reviewed journal, but that hasn't stopped some other physicists from taking a keen interest.

For decades, physicists have strived to come up with plausible mechanisms for time travel. Our best description of how space and time behave comes from Einstein's general theory of relativity, so researchers have been looking for some flaw in it – or some as yet unappreciated aspect – in the hope that this might do the trick. The time machine blueprints flowing from such endeavours have never got off the drawing board, but with the LHC we might have finally done it, albeit accidentally.

When the LHC is running at full throttle, it will imbue each of the particles travelling around its 27-kilometre circumference with around 7 teraelectronvolts (TeV) of energy. That may not be much in everyday terms: 1 TeV barely matches the kinetic energy of a flying mosquito. However, when concentrated into a subatomic particle – a trillionth the size of a mosquito – it can do extraordinary things to the fabric of the universe.

According to general relativity, everything in the universe is played out on a stage that has three dimensions of space and one of time. The strange thing about this space-time is that it gets warped by the mass and energy of the universe's contents. This is what lies at the root of gravitational attraction. The mass of the Earth, for instance, distorts the surrounding space, causing everything in its vicinity to feel a pull towards it.

It's harder to visualise the distortion of time, but it does happen to a tiny extent in the presence of any matter or energy. What's more, a large enough concentration of mass or energy can distort time so much that it loops back on itself like a rubber sheet rolled up to make a cylinder. These loops are known to physicists as "closed timelike curves" and they ought, at least in theory, to allow us to revisit some past moment in time.

The first person to show how a closed timelike curve could form was the Austrian mathematician Kurt Gödel. In 1949, he demonstrated that if the universe were spinning, relativity should allow this spin to create conditions in which time looped back on itself. If you could get yourself onto this loop, you would keep revisiting the same moment until you got off.

The idea that relativity allowed time travel bothered Einstein when Gödel showed him the results of his calculations, but it wasn't really a problem: to the best of our knowledge, our universe is not spinning, so time travel couldn't happen this way. Neither did the world end in 1976 when Frank Tipler of Tulane University in New Orleans, Louisiana, showed how an extremely massive and infinitely long, fast-rotating cylinder would create a similar opportunity to travel through time: it is, after all, not a machine that is going to get built any time soon.

Things got more interesting in 1988, when Kip Thorne and colleagues at the California Institute of Technology in Pasadena showed that wormholes, or tunnels through space-time, would allow time travel (*Physical Review Letters*, vol 61, p 1446). In this case a wormhole would close a loop in time. Travelling through it is a bit like taking a tunnel under a hill: you could get to the other side by going over the hill, but the tunnel gets you there faster. If you choose your wormhole carefully – or take an existing one and move its entrances around – you could even emerge from the wormhole before you went in at the other end.

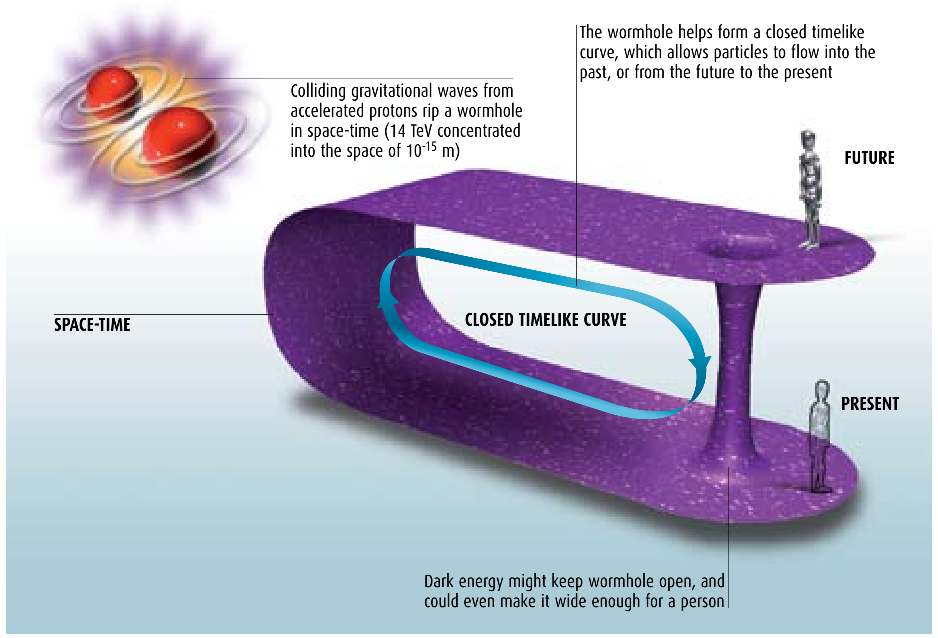
Space-time shock

This is where the LHC comes in. It could, Aref'eva and Volovich believe, create wormholes and so allow some form of time travel. Each particle travelling through the LHC creates a kind of shock wave in space-time, a gravitational ripple that distorts the space and time around it. When two such waves are heading towards each other, the outcome could be spectacular. Under certain conditions, the colliding gravitational waves will rip a hole in space and time.

What those conditions are depends on the precise nature of space-time – something we don't yet know enough about. While Einstein's relativity theory provides a description of ▶

HOW TO BUILD A TIME MACHINE

Extreme conditions at the Large Hadron Collider may produce wormholes in space-time. An advanced civilisation might be able to manipulate one of these to create a tunnel back to the point in time when the wormhole was first created



space-time's properties on a large scale, this is only an approximation. Finding out just how much energy it might take to rip holes in the fabric requires an understanding of quantum gravity – a microscopic description of space-time that is still beyond our reach.

Nevertheless, it is conceivable that the LHC could achieve the conditions needed for ripping a hole in space-time. The conventional view among physicists is that quantum gravity does not become important until you deal with phenomena that occur at energies of around 10^{16} TeV. However, a team led by Nima Arkani-Hamed from the University of California, Berkeley, has shown that quantum gravity could kick in at energies as low as 1 TeV (*Physical Review Letters*, vol 84, p 586).

Aref'eva and Volovich's speculation about strange space-time effects began with the realisation that the LHC might be powerful enough to make mini black holes. Two protons colliding with a combined energy of 14 TeV might create black holes 10^{-18} metres in diameter. That idea is intriguing enough, but it is only one possibility. Last year, Aref'eva and her colleagues were again playing about with Einstein's equations, looking for ways in which closed timelike curves might arise (see Diagram, above). It was then that they came across the possibility that the LHC might create a time machine (www.arxiv.org/abs/0710.2696). "We realised that closed timelike curves and wormholes could also be a result of collisions of particles," Aref'eva says.

The possibilities this raises are being taken seriously by some physicists. "This is an interesting paper," says J. Richard Gott of Princeton University in New Jersey, who suggested as long ago as 1991 that accelerating particles could be a route to time travel. In a paper published at the time in *Physical Review Letters*, he suggested that if super-energetic particles were aimed so that they missed each other by a small amount, they would warp the space-time around them enough that the interaction of their two warped space-times could form a closed timelike curve.

In Gott's calculations, however, the final outcome wasn't clear: the deformed space-times might well form a black hole instead of a time machine. "The twisting of space and time required to make a time machine are similar to that required to make a black hole," Gott says. Now Aref'eva and Volovich have calculated that wormholes and mini black holes have an equal chance of being created by the LHC, and that a wormhole might even appear as frequently as every couple of seconds.

None of this means we're going to be time travelling by Christmas, however. There are still plenty of obstacles to opening a time portal. Not least of them is the fact that these are mini wormholes, so only subatomic particles are small enough to travel through them. Probably the best we can hope for is that this might provide a signature of the wormholes' existence, Volovich says. If some of the energy from collisions in the LHC goes missing, it could be because the collisions created particles that have travelled into a wormhole.

The second obstacle is also to do with wormhole size. The mouth of a wormhole is like the mouth of a rubber balloon, in that it has a tendency to pull itself closed. The only way to avoid this is to prop the wormhole open with some strange kind of matter that exerts a push rather than a pull.

Is there any such stuff available? At this point, Aref'eva and Volovich extend their speculation into the mysteries of the "dark energy" that seems to be accelerating the expansion of the universe. Dark energy could, they say, be just what is needed to keep the entrance to a wormhole open, but to find out if that is even possible we need to know the answer to another crucial question: as space-time expands, does the density of dark energy increase, decrease or stay constant?

When physicists look at the way expanding space-time behaves, most interpret the observations as suggesting that the energy contained in every cubic centimetre of space-time stays constant: it is "persistent", not, as one might expect, "diluted" by the expansion of the universe. There are, however, a minority of physicists who are putting their money on a third possibility – that as space-time expands, every cubic centimetre gains ever more energy. If dark energy did have this "phantom" nature, space-time would contain an inherent push that could keep the mouths of LHC wormholes open – and perhaps even grow them big enough for people to pass through. "The observational evidence still allows for phantom energy," says Robert Caldwell, a physicist at Dartmouth College in Hanover, New Hampshire.

Wormhole fingerprint

Unfortunately, we just don't know yet which of the three possibilities is right. Francisco Lobo of the University of Lisbon in Portugal is among the minority who favour the existence of phantom energy – the kind Aref'eva and Volovich say would prop wormholes open. However, just as we're getting ready to go back to the future, Lobo throws his own spanner in the works. "Even if one could, in principle, detect a wormhole signature it does not guarantee the presence of a time machine," he says. We might see the fingerprint of a wormhole at the LHC, just as we might see the indicator of a black hole being formed, but that's not enough to create a useful loop in time, Lobo reckons.

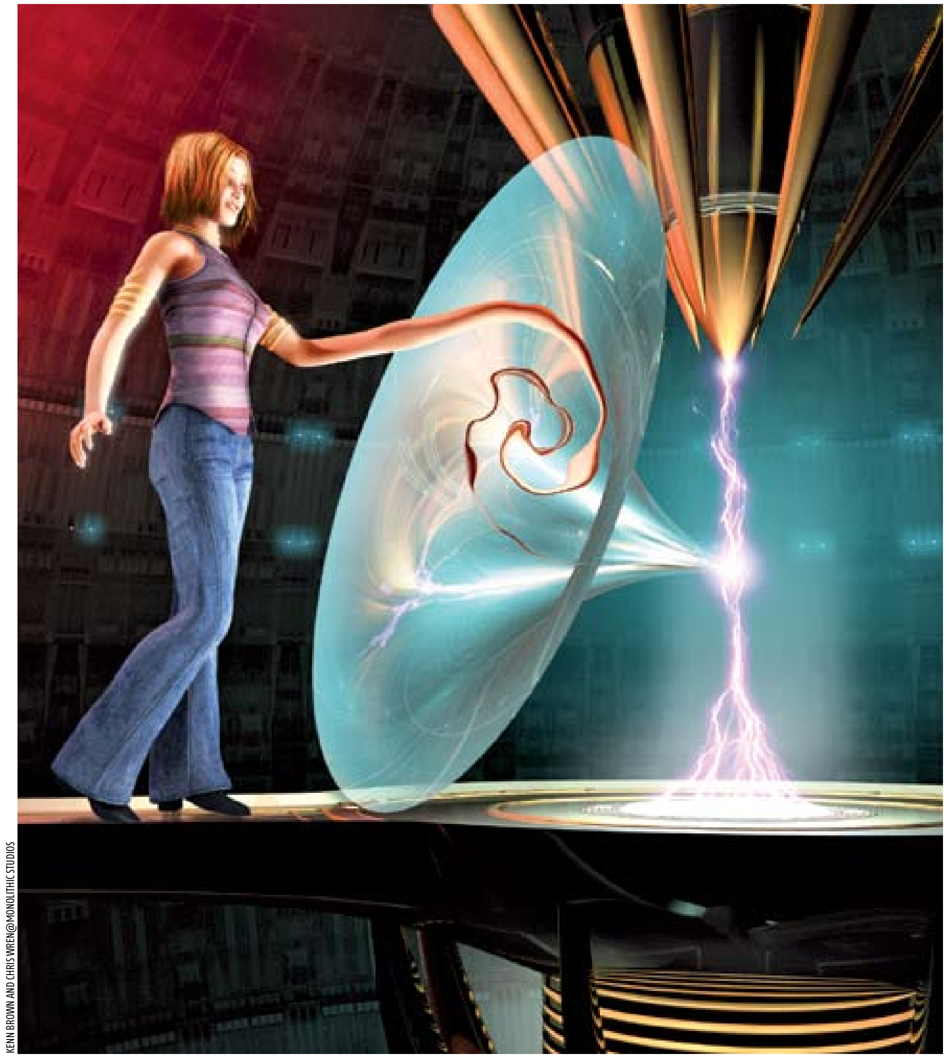
A wormhole is a loop protruding from "normal" space-time, like a handle protruding

"If fast-moving particles and phantom energy create a wormhole in Geneva, future civilisations might be able to pay us a visit"

from a teacup. If you want to turn the wormhole into a time machine, you have to make sure the two ends of the handle meet the cup at just the right points in time. "One would have to create a time-shift between the wormhole mouths," Lobo says.

Various schemes have been proposed to create such a time-shift, but all of them are exotic to say the least. Anchoring one end of a wormhole to a neutron star might do the job, for instance. The intense gravitational field of the star slows time, so the wormhole mouth near the star would develop a time difference with respect to the other mouth. It is conceivable that a time traveller could then jump in, emerge at some point in her past, then travel through normal space to the other end of the wormhole and hang around waiting to watch herself jumping in. It's not the kind of operation we are going to be capable of in the foreseeable future, as Lobo points out.

Yet who knows? Perhaps future civilisations might work out how to stabilise and grow a wormhole, then manipulate the two mouths in order to create a time tunnel. If a combination of fast-moving particles and phantom energy does create a wormhole in Geneva this year, such an advanced civilisation could find it in their history books, pinpoint the moment, and take advantage of their technology to pay us a visit.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This possibility forces us to confront the many paradoxes that time travel raises. The classic example is the time traveller who goes back to kill his grandfather before his own father is conceived – thus ensuring he is never born. Scenarios such as this prompted Stephen Hawking to suggest in 1992 that the laws of physics actually conspire against time travel. His "chronology protection conjecture" says that creating loops in time that would allow time travel has a kind of negative feedback, giving rise to physical phenomena that act to block the loops – as if there were a causality enforcement agency.

Aref'eva doesn't fear these time cops, though. "In general relativity, one cannot just assert that chronology should be preserved without careful analysis," she says. There are many solutions of Einstein's equations that permit such paradoxes to arise, she points out; it is arrogant to declare that these situations can't be manifest in reality just because we can't see how they will play out. Perhaps, she says, the paradoxes will answer questions about free will or allow us to sift through the interpretations of quantum theory. Maybe you would find yourself unable or unwilling to kill your grandfather, or end up in a parallel universe where killing your grandfather would make no difference in the universe from whence you came. Until we build a time machine, we just can't know.

For now our best hope of finding out about the limits of temporal law enforcement is to let the physicists and engineers carry on with their preparations at the LHC. Sure, there are unresolved issues about the scale at which quantum gravity kicks in; we are still arguing over whether the universe contains phantom energy; and we don't even know if we have the likelihood of black holes and wormholes pinned down accurately. Nevertheless, the slim possibility remains that we will see visitors from the future in the next year.

Wouldn't it be better to be prepared than not? Perhaps now is the time to increase the staffing levels at Geneva's tourist information centre. And if you are a grandfather, you might want to check the small print on your life insurance. ●