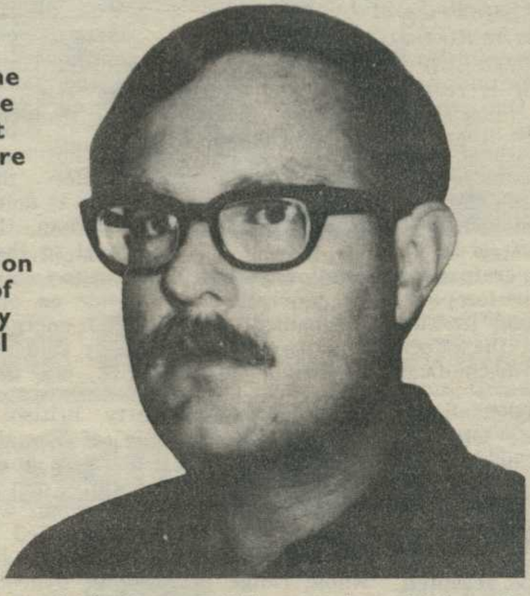
Building a time machine

According to the equations of classical general relativity theory, it is possible in principle to build a time machine. "Commonsense" says this is impossible—but commonsense has been wrong before

Dr John Gribbin has been talking to Dr Frank Tipler, of the University of Texas at Austin

One of the shortest of SF writer Larry Niven's offerings has the catchy title *Rotating Cylinders and the Possibility of Global Causality Violation,* a title which the author admits he stole from a mathematics paper by Frank Tipler. The story depends on the assumption that the work described by Tipler in that paper can be taken at face value, implying that it is possible to construct a working time machine based upon the rotation of a very long, massive and suitably rigid cylinder constructed in space. This particular paper was published in 1974 (*Physical Review D*, vol 9, p 2203), and Niven's light hearted variation on the theme is currently available in the collection *Convergent Series* (Del Rey/Ballantine, New York, 1979). But five years is a long time in science, and theories which looked good in 1974 may not stand up to scrutiny in 1979 or 1980. So, inspired by the reprint of the Niven story, I contacted Frank Tipler to find out whether he still believes that time travel is possible. I hope you are sitting comfortably, for his response in plain English is that "my current view is that there is indeed a real theoretical possibility for causality violation in the context of classical general relativity theory", although he does follow this remark up with the *caveat* "that is, I feel the question is still open". And he has directed me to a continuing series of his papers, which have been published since 1974 and which spell out the mathematical basis of that plain English remark.

Does Tipler believe that time travel is possible . . . "my current view is that there is indeed a real theoretical possibility for causality violation in the context of relativity theory . . . that is, I feel the question is still open"



"Causality violation" is specialist terminology equivalent to what you or I mean by "time travel". The point is that if time travel in the fullest sense is possible, then effects can be seen to precede their cause, instead of following them. Causality is violated, for example, if the light in my room comes on, and *then* I close the switch which allows current to flow; or if the winner of the 3.45 at Newmarket is announced, and *then* I pop back to 3.30 to place my bet at Ladbrokes. There is a widespread and general assumption among mathematicians and physicists that causality cannot be violated—but this is no more than an assumption, based on the commonsense view ingrained by everyday experience. So deeply is this view ingrained that any theory which allows, or predicts, causality violation is usually regarded, on those grounds alone, as a "bad" description of reality. But this is only a prejudice, akin to Einstein's remark "God does not play dice with the Universe". More recently, astrophysicist Stephen Hawking said "God not only plays dice, he throws them where they can't be seen"; Tipler and a few others argue that we should at least keep open minds at present concerning the possibility that God has an equally cavalier attitude towards causality.

The religious overtones are appropriate, as Niven noticed. The denouement to his story depends on the "fact" that although in principle a working time machine could be built, every time one nears completion some natural disaster, such as a supernova explosion, destroys it. The Universe, or God, is seen as "abhorring causality violation" in the way that it was once said to abhor a vacuum. It is a good story; what of the mathematics?

General relativity is the best mathematical description of the Universe—of space-time—that we have, and has stood up to every test applied so far. So to answer the question "is time travel possible?" the best tool available to the mathematician is general relativity. Tipler has broken the question down further, into three main parts:

1) Do the equations allow in theory for the existence of journeys through space-time in which the traveller returns to his starting point in both space *and* time, having travelled "backwards in time" for part of the journey?

2) If so, is it possible for the conditions under which such journeys are possible to arise naturally?

3) And is it possible, in principle at least, to create such conditions artificially, that is to build a working time machine? It turns out that the answer to all three questions is "yes"!

First, the framework within relativity theory. What we learn from special relativity is that time intervals experienced by people and measured by physical clocks depend on the particular path they follow through space-time. If two space-time paths coincide initially and intersect later, and one path is accelerated while the other is not, then the time length of the accelerated path will be shorter—less time will have passed for the traveller following this path. But we can never exceed the speed of light (at which time would stand still for a hypothetical observer), and can never travel backwards in time. Our passage through the four-dimensional fabric of space-time is confined within a region bounded by paths corresponding to light rays radiating from the here and now, a region called the "future light cone". And our knowledge of past events in the Universe is confined to information coming in from a similar four-dimensional cone extending into the past, the "past light cone". In practice, relativists compress the

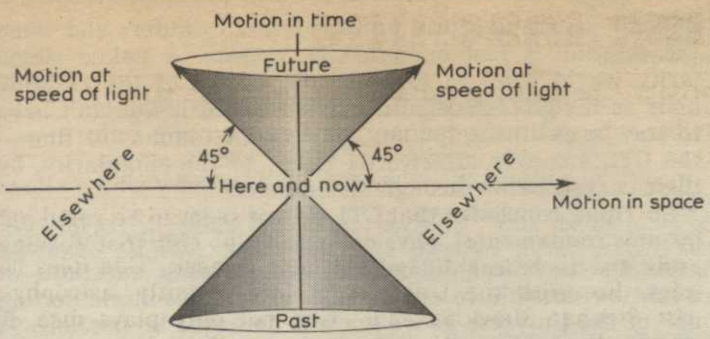


Figure 1 The standard space-time diagram used by relativists compresses "space" into a two-dimensional plane with "time" represented by the third dimension

three dimensions of space into one representational dimension, allowing them to plot two-dimensional diagrams on paper, with the flow of time represented "up the page" and movement in space "across the page" (see Figure 1). On such a space-time diagram, one quarter of the page represents the future, one quarter the past, and fully half of space-time is inaccessible, and dubbed "elsewhere".

But special relativity takes no account of the effects of gravity, and one such effect, spelled out by general relativity, is that the presence of matter in a region of space-time causes nearby light cones to "tip over" in the direction of the matter. If the matter is rotating, then it distorts space-time so that the light cones tip over in the direction of rotation. And if the rotation rate and the strength of the gravitational field are large enough, then the light cones tip over so far that the coordinate used in diagrams like Figure 1 to measure space (conventionally called the ψ-coordinate) now begins to measure time. In practical terms, the roles of space and time have been reversed, and by the entirely legitimate process of changing his ψ-coordinate within his local region of space time, a traveller would move through time. Referring to the diagram shown here as Figure 2, Tipler says "a traveller could begin his journey in weak field regions—perhaps near the Earth—go to the tipped-over light-cone region and there

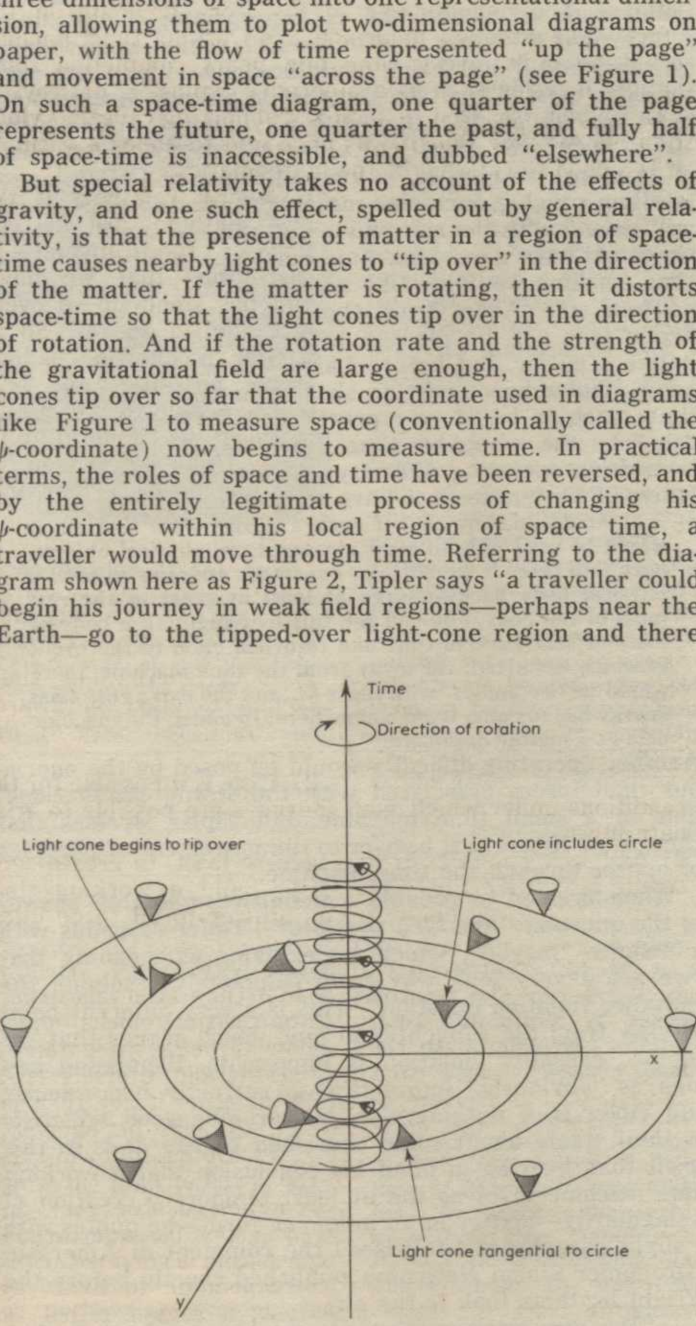


Figure 2 Near a massive rotating object, space-time is distorted so that the "light cones" in local regions tip over. A traveller, or message, can only move forward within a light cone—but if the light cone points backwards in time, time travel is possible

move in the direction of negative time, and then return to the weak field region, without ever leaving the region defined by his local future light cone. If he travelled sufficiently far in the minus-*t* direction while in the strong field region, he could return to Earth before he left—he can go as far as he wishes into the Earth's past. This is a case of true time travel." In other words, question 1 has been answered in the affirmative—general relativity does imply the theoretical possibility of causality violation. But is it practicable?

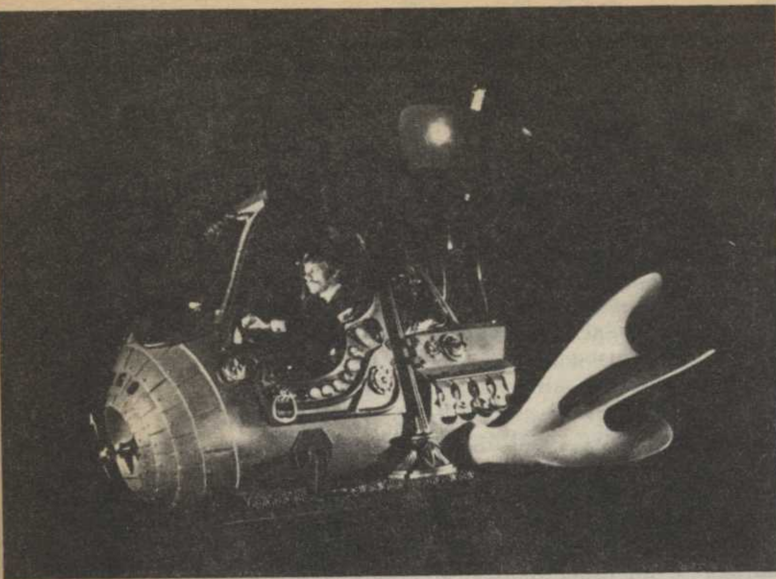
There is no guarantee that because a region of space-time like that depicted in Figure 2 *can* exist then such a region *will* exist. Crucially, how much mass must there be in the rotating massive object, and how fast must it be rotating, for causality violation to occur? A slightly more subtle point is that as the light cones are not tipped over until the massive rotating object comes into being, there is no way to travel further back in time than the creation of the "time machine", whether this is natural or an artifact. If we built a time machine now, we couldn't travel back to study the ancient Greeks; but if we found a natural time machine left over from the creation of the Universe, then we could.

Closed timelike lines

Some of these questions have been tackled by various relativists over the years, including Einstein himself and Gödel, who gave his name to a class of cosmological models involving a rotating universe. If the whole Universe is rotating, then there is definitely no problem about time travel, and a feature of the Gödel universe is that it contains "closed timelike lines", that is it allows for causality violation. A closed timelike line (CTL) is simply a path through space-time that returns to its starting point in both space *and* time, making a closed loop. To do so, the path must, of course, loop backwards in time somewhere along the way. "Of course," say the cosmologists, "that proves our Universe is *not* rotating." The argument may be dubious, but as it happens, observations do not show any significant rotational effects for the Universe we live in. To find a natural time machine we will have to focus down on more local regions of space-time, and lesser quantities of matter.

This is where the mathematics get hairy. You'll have to take most of the conclusions which follow on faith, partly because I don't trust myself to report the arguments with 100 per cent accuracy, and partly because our printers can't cope with the mathematical symbols anyway. But for maths buffs, the facts are all spelled out in *Physical Review D*, vol 16, p 3359; *Annals of Physics*, vol 108, p 1; *Physical Review Letters*, vol 37, p 879; and the contribution by Tipler, C. S. Clarke and G. F. R. Ellis to the book *General Relativity and Gravitation: One Hundred Years After the Birth of Albert Einstein*, vol 2, p 97. edited by A. Med (Plenum. London, 1980).

Closed timelike lines, of course, are paths through space-time which return to their starting point. General relativity permits closed timelike lines (CTL), but the standard way to test the physical reality of solutions to Einstein's equations is to change the parameters being fed in to the equations ("perturb the initial conditions") to see if the same solutions still come out. But


'Time after Time'/Columbia-EMI-Warner

it is hard to test whether CTL are stable when the initial data are disturbed because if CTL exist then it is hard to define what you mean by "initial" in applying the equations to them. In terms of the practicality of the existence of CTL in our Universe, however, Tipler's calculations have come up with one very important conclusion. A time machine cannot be created from ordinary material under ordinary conditions; CTL can arise only if at least some matter passes through such extreme conditions that we cannot trust our knowledge of material behaviour—if a singularity is created. A singularity is a region where the matter density becomes infinite, and there is no way in which matter with arbitrarily large density can be considered "ordinary". On the other hand, most relativists accept that singularities do occur in the ultimate collapse of matter within black holes. Such a singularity cannot be seen, because it is surrounded by an event horizon, the surface at which the escape velocity from the region exceeds the speed of light. Nothing, including light, can escape from the region within the event horizon—hence the name "black hole"—but the equations of relativity theory tell us what is likely to happen close to the concealed singularity. The snag there, for would be time travellers, is that while it might be possible to cross into the black hole and travel backwards in time, there would be no way to cross out over the hole's event horizon to return to your starting point in space. You cannot, in other words, have a practical time machine without a *naked* singularity, one that is not surrounded by a black hole event horizon—in other words, a one-way gravitational well.

Black holes aren't black

All is not lost, however, as Stephen Hawking has shown that "black holes aren't black", and that they tend to "evaporate" over a very long period of time, eventually exploding outwards and exposing a singularity to outside view. If the singularity also had angular momentum—if it was rotating—it would be a working time machine with CTL. Such a time machine could arise naturally, from a small black hole left over from the big bang, so that the answer to question number 2 is also affirmative. Or we might, in principle, be able to capture a mini-black hole and cool the space around it, encouraging it to evaporate until a naked singularity formed. In principle, it would even be possible to manufacture a small black hole in the first place, using powerful nuclear fusion devices. And there is also the possibility picked up by Larry Niven—take a compact rotating body and speed up its rotation far enough, while somehow ensuring that it doesn't collapse along its axis (which, says Tipler sadly, would be very difficult to arrange for a finite rotating cylinder) and when the rotation is fast enough CTL appear. A naked singularity would have to form in the centre of the rotating body as the CTL come into existence, but it wouldn't have to stay in existence for any appreciable amount of time—the CTL are ever afterwards "tied" to the singularity, by their curved paths through space-time.

So Tipler concludes that CTL do not seem to be ruled out by any fundamental physical principle, and that leaving aside the technical difficulties, and stability questions, it would be possible to create CTL after the initial "setting up" of the Universe as we know it. It would be possible, in other words, by some very sophisticated and expensive engineering, to set up a time machine.

Some idea of the engineering difficulties is provided by some very "iffy" numbers Tipler quotes. *If* the infinite rotating cylinder approximation is valid then a length to radius ratio of about 10:1 is appropriate; *if* this finite cylinder has the same field in the CTL region as an infinite cylinder; and *if* stabilising could be done without the need for extra mass (Tipler stresses that in his view it is unlikely to be possible *at all*!); *then* with a cylinder of mass density 10^{14} g/cu.cm (the density of a neutron star, or the nucleus of an atom), a radius of 10 km and length of 100 km or so, totalling roughly one solar mass, and rotating twice every millisecond with the rim moving at half the speed of light, we would have a working time machine. In other words, a time machine would be like an elongated, rapidly rotating neutron star. Apart from the stability problem, science fiction fans will be pleased to hear, this is not so much unlike a pulsar. But before Larry Niven takes up his pen again, Tipler has a parting shot to impart. Would such a time machine be of any practical use? In discussing its value to the would-be time traveller, Tipler raises an interesting operating difficulty which even the most imaginative SF writers seem to have missed:

> "I would imagine that if such a device were created, it would be used only to send messages, no physical objects, back into time. It would take enormous energies to send a physical body back—energy at least as great as the rest mass of the body. you can see this by imagining a body of mass M sent back in time and returned close to the event at which it started; far away from the time machine, there would be *two* bodies with mass M, and the extra rest-mass energy has to come from somewhere. In effect, the machine acts as a matter duplicator."

Another operating difficulty would be posed by the enormous tidal forces associated with the strong gravitational field of a small time machine; but Tipler stresses that there is no theoretical barrier to the movement of particles of matter through the time machine.

When pressed to provide a definitive, quotable answer to the question "Are CTL possible?", Tipler responds with a definite "maybe", which he explains as meaning that "we are a very long way from completely resolving the causality violation question". This is a very different point of view from the conventional one, which argues that "of course" causality violation is impossible. Dismissing any idea as "obviously" impractical is certainly bad science, and Tipler is, if nothing else, encouraging good scientists to think again about some cherished beliefs. It is in this spirit that, bearing in mind his conclusion that a working time machine involves the at least temporary creation of a singularity—matter in an *unknown* form—he quotes with a slight paraphrase (italicised) the comment of American astronomer Simon Newcomb published shortly before the Wright brothers took to the air:

> "The demonstration that no possible combination of known substances, known forms of machinery, and known forms of force can be united in a particular machine by which men shall *travel back in time*, seems to the writer as complete as it is possible for the demonstration of any physical feat to be." □