The Alternate View

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SHOOTING WORMHOLES TO THE STARS

I chaired the "Exotic Science" session at the DARPA/NASA sponsored 100 Year Starship Symposium, held in Orlando, Florida, September 30 to October 2, 2011. There, the propulsion experts pulled out all the stops in attempting the design of a starship that might reach the stars in a human lifetime, and they essentially failed, even when invoking nuclear or antimatter energy sources. The stars are very far away. Reaching them is a very difficult problem with no easy solutions . . . except, perhaps, for one partially baked idea that was introduced in my column in the May 1990 *Analog*. Looking back at my old column, I realize that it had a few mistakes and could have been presented better. So, in the new DARPA context, let's revisit the idea here.
First, let us assume, following the lead of Thorne, Morris, and Yurtserver, that we can snatch microscopic wormholes from the quantum foam and stabilize them. If we keep a wormhole mouth microscopic in mass and size, it behaves much like a fundamental particle with a very large mass, perhaps somewhat in excess of the Planck mass of 21.8 micrograms. For the purposes of calculation, let us assume that we can produce a stabilized microscopic wormhole with a mass of 10 Planck masses or 218 micrograms. Could such an object exist? Visser has described wormhole solutions to Einstein's equations of general relativity that are flat-space wormholes stitched together across a cut and co-stabilized by a tiny loop of negative-tension cosmic string. A wormhole like this might occur naturally in the aftermath of the Big Bang and might have the size and mass described above.

Next we take the two wormhole mouths of this object and thread lines of electrical force through them, until we have passed about 20 coulombs of charge through the wormhole. This can be done, for example, with a 20-microampere electron beam passing through the wormhole for about 12 days. The result is that the wormhole mouth will now have the same charge-to-mass ratio as a proton and will behave like a proton in the electric and magnetic fields of a particle accelerator.
Now we transport what we will call the "traveling wormhole mouth" to Meyrin, Switzerland near Geneva and put it into CERN's new Large Hadronic Collider (LHC) there. The other wormhole mouth remains in our laboratory, along with various stabilizing and steering equipment. We assume that by the time we are able to do this, the LHC will have achieved its full design capacity and will be able to accelerate each of its colliding proton beams to 7.0 TeV (7.0 x 10^{12} electron volts). We use the LHC to accelerate the wormhole mouth to the same energy per unit rest mass as a 7-TeV proton, extract the beam that contains it, point it at a star of interest, and send it on its way. (Presumably, we would do this in an operation with a number of wormhole-mouths pointed at a selection of candidate stars that might have Earth-like planets in orbit around them.)
A proton with a total energy of 7.0 TeV will have a Lorentz gamma factor ($\mathbf{g = [1 - (v/c)^2]^{1/2}} = E/M$) of 7,455. The accelerated wormhole mouth will have the same Lorentz factor. This is the factor by which the total mass-energy ***E*** of the proton moving at this high velocity ***v*** exceeds its rest mass ***M***. It is also the factor by which time dilates, i.e., by which the clock of a hypothetical observer riding on the proton would slow down. The wormhole is traveling at a velocity that is only a tiny fraction less than the speed of light, so it travels a distance of one light-year in one year. However, to an observer riding on the wormhole mouth, because of relativistic time dilation the distance of one light year would be covered in only 1/7,455 of a year or 70.5 minutes.
Moreover, back on Earth, if we peek through the other wormhole mouth that is at rest in our laboratory, we see the universe from the perspective of an observer riding on the traveling wormhole mouth. In other words, in 70.5 minutes after its launch from CERN, through the wormhole we will be able to view the universe one light year away. Later, in 11.7 hours, we will view the surroundings 10 light years away. In 4.9 days, we will view the surroundings 100 light years away. And so on.
This is a remarkable result. How is it possible that, if the traveling wormhole mouth requires 100 years, as viewed from Earth, to travel 100 light years, we can view its destination as observers looking through the wormhole in a bit less than five days? It is because, as Morris, Thorne, and Yurtserver pointed out, the special relativity of time dilation makes a wormhole with one high-velocity mouth into a time machine. The wormhole mouth, 100 light-years away, connects *back in time* to its departure point only five days after it left. From our point of view, it has moved 100 light years at a speed of 7,455 c.
But could the traveling wormhole mouth be aimed so accurately from its start at CERN that it might it actually pass through another star system many light years away, to survey its planets and so on? And could it stop when it got there? To answer these questions, we must understand the idea of "back reaction" as it applies to wormhole ends. The way wormholes work, it is not possible to change the amount of conserved quantities like mass-energy, electric charge, and momentum in the local space region around the wormhole mouths. If an electric charge disappears into a wormhole mouth, the entry mouth acquires the quantity of electric charge that passed through it (think of the lines of electric flux threading the wormhole). Similarly, if a mass goes through, the entry mouth becomes more massive. And if a high momentum particle goes through, the entry mouth is pushed forward with that momentum. In this way, the local mass-energy, charge, and momentum in the vicinity of the wormhole mass do not change. No mass-energy, charge, or momentum can magically appear or disappear.
Similarly, if a positive electric charge emerges from the exit wormhole mouth, the mouth acquires an equal and opposite charge, so that the net charge in the region does not change. An emerging massive particle

causes the exit mouth to lose mass-energy, and an emerging high-momentum particle gives the exit mouth a recoil momentum in the opposite direction. This is called back reaction. (We note that in the May 1990 column we suggested refueling a starship though a wormhole. That would not work, because of back reaction effects.) The effect of back reaction in changing the mass of a wormhole mouth raises a flag of caution. Since we have not specified how the wormhole is stabilized against its intrinsic tendency to collapse and close off, we do not really understand the rules concerning the mass of the traveling wormhole. In particular, we do not understand how massive it can be, and how small the mass can be allowed to become before stability is lost. Can the mass go to zero? Can it go negative? Managing the masses of the two wormhole mouths during steering and deceleration maneuvers is likely to be a major problem in implementing the steering scheme described below.

Assuming the mass problem can be managed, the momentum back-reaction can be used to steer the traveling wormhole mouth. The direction of travel, as viewed through the wormhole, can be monitored. Course corrections can be made by directing a high-intensity light beam through the laboratory-based wormhole mouth at right angles to the direction of travel. The exit mouth will lose a bit of mass-energy in this process, but it will also be gaining some mass-energy as interstellar gas passes through it, which may compensate. We note that, in terms of momentum change vs. mass gain of the wormhole mouth, the use of light for steering is preferable to high-energy particles, even though the momentum carried by light is only its energy divided by the speed of light.

Assuming that precision steering can be accomplished, stopping is not too difficult. The exit mouth can be steered to make passes through the upper atmospheres of planets or to have grazing collisions with atmosphere of the star itself, until the great initial velocity has been dissipated. In this process, considerable mass will pass through the traveling mouth, and it will gain this mass-energy by back reaction. It can tour the star system, propelled by high-momentum particle jets incident on the stay-at-home mouth in the laboratory. Such steering will tend to reduce the mass of the wormhole mass, partially compensating for the mass-gain it received in decelerating, and perhaps it could be used for sampling planetary atmospheres.

Now that the wormhole mouth has arrived at the star system of interest, a survey of the planets can begin. We assume that we have laboratory control of the diameter of the wormhole mouth, and that it can be enlarged to a diameter that is convenient for sampling. If a habitable planet is found, the wormhole mouth can be brought to its surface, and samples can be extracted through the wormhole and analyzed (perhaps sending compensating mass back in the other direction to keep the wormhole mouth masses in balance).

Ultimately, when the survey is complete, the wormhole can be expanded, permitting robot precursors, explorers, colonists, and freight to move through. Again, the mass of the wormhole mouths would have to be managed, moving equal masses in the two directions during wormhole transits, perhaps by sending compensating masses of water through pipes. This scheme could allow very rapid travel to and colonization of various star systems containing Earth-like planets. Thus, if stable wormholes are possible at all, they may represent a path to the stars that would sweep away many of our previous concepts and prejudices about how the stars can and should be reached.

Is there any problem with causality created by using what is in essence a time machine to reach the stars? Perhaps. The issue is whether a time-like loop might be established. Although the space-time interval from some event at the distant star to the observation of that event on Earth, as viewed through the wormhole, represents two-way communication across a space-like separation, there is no causality problem because there is no loop.

However, a causality problem could arise if similar but independent wormhole connections were established with accelerated wormhole mouths sent from the distant star system back to Earth, or even to another star system that had been similarly contacted by Earth. In that case, transit through one wormhole followed by return through the other would constitute a time-like loop. Stephen Hawking has suggested that Nature will prevent the establishment of any time-like loop through an exponential rise in vacuum fluctuations that would destroy some elements of the incipient loop. Thus, an attempt to set up the second link might result in an explosion. The moral is that such wormhole connections must originate from only one central site. Any attempt at replication from another site might lead to disaster.

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This brings us to a variation of the famous Fermi Paradox: if interstellar wormhole transport is possible, shouldn't the technologically advanced civilizations of our galaxy already be sending tiny accelerated wormhole portals in our direction? Then where are they?

Perhaps they are already here. Cosmic ray physicists have occasionally observed strange super-energetic cosmic ray detection anomalies, the Centauro events. These are cosmic ray particles with incredibly high energies that, when striking Earth's upper atmosphere, produce a large shower of particles that contains too many gamma rays and too few mu leptons, as compared to more normal cosmic ray shower events. The Centauro events presently lack an explanation based on any known physics. However, an accelerated wormhole mouth with a large electric charge should have a large gamma-ray to mu-lepton production ratio in such collisions, since it would have large electromagnetic interactions but no strong or weak interactions with the matter with which it collided.

It is interesting to contemplate the possibility that some advanced civilization may be mapping the galaxy with accelerated wormhole portals, sending little time-dilated observation points out into the cosmos as peep-holes for viewing the wonders of the universe. And perhaps, when a particularly promising or interesting scene comes into view, the peephole is halted and expanded into a portal through which a visitor can pass.

Clearly we need to gain much more understanding of wormholes. They could provide our pathway to the stars.

AV Columns Online: Electronic reprints of over 160 "The Alternate View" columns by John G. Cramer, previously published in *Analog*, are available online at: http://www.npl.washington.edu/av.

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