Wormhole entanglement gives space-time the bends

26 July 2013 by **Adam Becker**, Santa Cruz
Magazine issue 2927. **Subscribe and save**

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Can's open, wormholes everywhere *(Image: Jonathan Kantor/Taxi/Getty)*

SPACE-TIME, the very fabric of our universe, may be a tangled place. Entanglement, a feature of quantum mechanics that links objects over great distances, could be responsible for its structure. What's more, entanglement may fill the universe with a thicket of cosmic tunnels called wormholes.

All these ideas fall out of a new theory that is making inroads into unifying gravity, which operates on large scales, with quantum mechanics, the science of the very small. A successful theory of quantum gravity is one of the biggest goals of modern physics.

The theory also raises the bizarre possibility of using wormholes to enable a futuristic version of a lover's leap. Two people separated by hundreds of light years could in principle meet inside an "entanglement wormhole". But their love had better be strong: there is no escape from a quantum wormhole, forcing the pair to stay together until they die (see "Wormhole romance: the modern tragedy of Alice and Bob").

It all sounds a little wild, but the ideas are gaining traction and sparked lively discussion at a recent meeting of the top minds in theoretical physics and philosophy at the University of California, Santa Cruz. "This is all crazy," Leonard Susskind of Stanford University in California, one of the brains behind the new kind of wormhole, told the conference on 5 July. "It's also believed to be correct."

The connection between entanglement and wormholes was first proposed a month ago. Its backstory, however, began in 2009, when Mark Van Raamsdonk at the University of British Columbia in Vancouver, Canada, proposed a way to connect the bendy space-time of general relativity, Einstein's theory of gravity, with quantum mechanics, which usually assumes an unrealistic, rigid space-time.

Van Raamsdonk's innovation involved the fields that appear in a quantum view of the universe, such as the electromagnetic field and the more exotic Higgs field.

Neighbouring fields are generally more entangled with each other than with regions farther away in space or time. This led Van Raamsdonk to wonder if entanglement has a role in space-time's geometry. Sure enough, he was able to show that altering the entanglement of quantum fields can alter the shape of space-time, making it flexible. "If you change the pattern of entanglement, you also change the geometry of space-time," says Juan Maldacena of the Institute for Advanced Study in

Princeton, New Jersey.

Last month, Maldacena and Susskind enriched Van Raamsdonk's idea by adding wormholes to the picture. They suggested that wormholes, previously only described by general relativity, could also emerge from entanglement.

The wormhole addition checks out, says Van Raamsdonk, and he has fleshed out a concrete example in which a black hole radiates away half of its mass via a process called Hawking radiation, and then that radiation itself collapses to form a second black hole. "Now you have two black holes, maximally entangled," says Van Raamsdonk. "Do the exact solution and you find you have two black holes connected by a wormhole." That ups the likelihood that space-time's bendy structure comes from entanglement – and that wormholes do too (arxiv.org/abs/1307.1796).

Another compelling reason to take wormhole entanglement seriously is calculations that suggest it provides a way out of a recent conundrum known as the black hole firewall paradox.

The paradox, first outlined last year, goes something like this. The particles that black holes emit via Hawking radiation should be entangled with the black hole, but also with each other – and quantum physics forbids such promiscuity. But if you break the entanglement between the black hole and its radiation, you get an intense high-energy blast immediately inside the event horizon of the black hole – a firewall. This violates general relativity, which says that a black hole's interior should be smooth. But, according to Susskind and Maldacena, if the entanglement gives rise to wormholes, this changes things and there may be no violation of quantum monogamy, removing the need to break the entanglement.

Joseph Polchinski at the University of California, Santa Barbara (UCSB), one of the originators of the firewall paradox, is not convinced. In a recent response to Maldacena and Susskind, he – along with another of the original firewallers, Donald Marolf, also of UCSB – showed that some black holes could still have firewalls even if entanglement does lead to wormholes (arxiv.org/abs/1307.4706).

No matter how the firewall paradox shakes out, entanglement is likely to remain important in the hunt for quantum gravity. "The importance of entanglement for determining space-time structure is something that, three years ago, only a few of us were thinking about," says Van Raamsdonk. "Now, a lot of people are realising that it's an important piece of our thinking about quantum gravity."

What if entanglement, which Einstein called "spooky action at a distance", turns out to be key to understanding the warping of space-time, first described by Einstein's own equations? "It's an amazing statement if it's really true," says Van Raamsdonk. "It's a really exciting thing to be working on."

This article appeared in print under the headline "The great quantum space-time tangle"

From issue 2927 of New Scientist magazine, page 10-11.