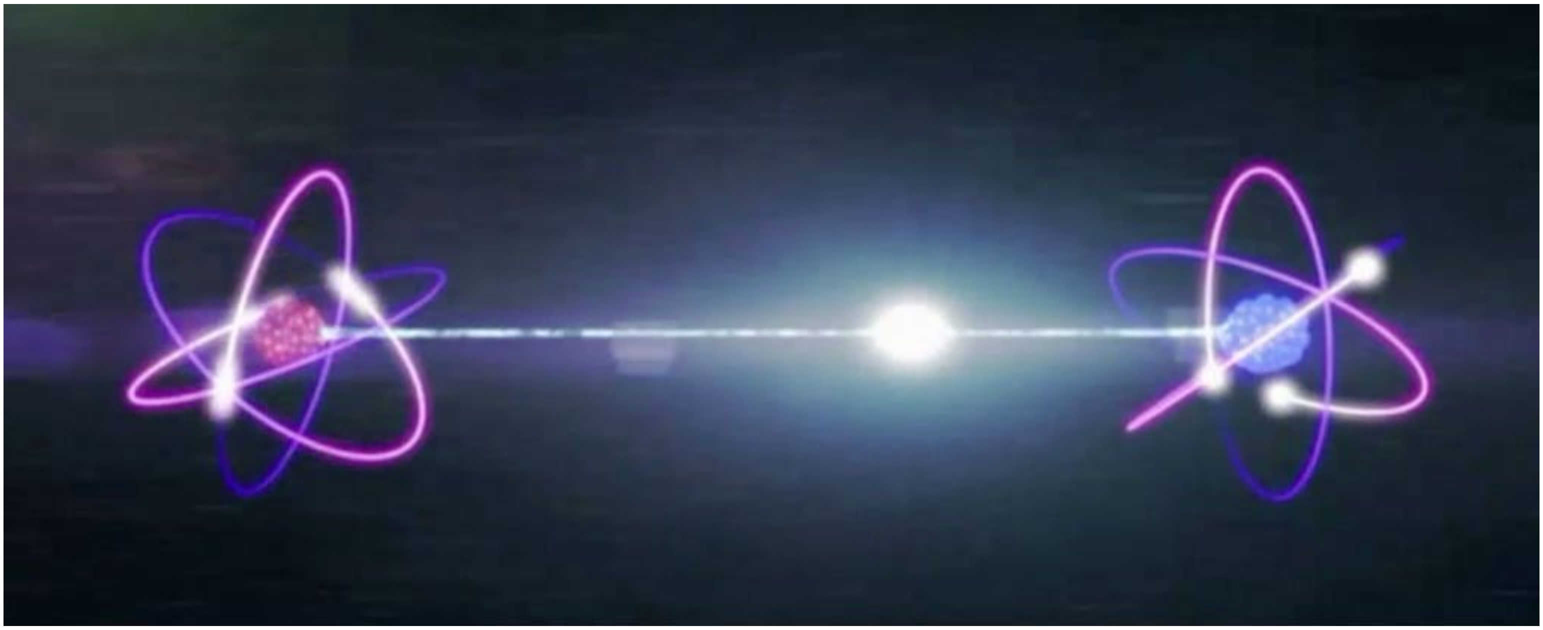

Sorry, Einstein - physicists just reinforced the reality of quantum weirdness in the Universe

There's no avoiding that "spooky action at a distance."

BEC CREW 8 FEB 2017

One of the strangest phenomena you're likely to come across in all of science is quantum entanglement - where two particles interact in such a way that they become deeply linked, and essentially 'share' an existence, even if they're light-years apart.

Einstein famously couldn't get on board with this idea, and ultimately decided that it was just too weird to be true. But a new experiment has just made the strongest case yet for the reality of quantum entanglement, so it looks like our Universe is just as bizarre as we suspected.

"The real estate left over for the skeptics of quantum mecha considerably," one of the team, David Kaiser from MIT, told J Phys.org.

"We haven't gotten rid of it, but we've shrunk it down by 16 magnitude."

As a concept, quantum entanglement is one of the most difficult things to prove, because while physicists can easily observe it - entangled particles are the very basis of quantum computing - it's impossible to know for sure that hidden variables aren't messing with the results to make it only *look* like two particles are inexorably linked.

If you're not familiar with quantum entanglement, imagine two particles - they can be separated by a few metres, or a couple of light-years, but regardless of how far apart they are, they're entangled.

That means, for some inexplicable reason, these distant particles are able to maintain a special connection with each other, so that if one particle is measured, physicists will know the exact measurements of its partner.

That's weird enough on its own, but what makes this phenomenon even stranger is the fact that neither of these particles have 'built in' properties - their properties are only defined once they're measured, so how can the partner particle have definable properties when we haven't even nailed them down yet?

Despite the fact that countless experiments over the past century have confirmed quantum entanglement behaviour, no one can fully explain it, and Einstein himself remained a skeptic until the very end, dismissing it as "spooky action from a distance".

Einstein didn't deny that particles appeared to be quantum entangled, but argued that some hidden variables were at play that made this so.

This prompted physicist John Bell to establish a kind of 'test' in the 1960s that could measure the probability that the appearance of entanglement was either down to actual entanglement, or some other variable that made it look like entanglement.

Bell test experiments - also known as Bell's inequality experiments -

involve performing independent measurements on each entangled particle to see which option bears out most convincingly.

"Bell showed that, statistically, correlations between the results, once above a certain threshold limit, could not be explained by particles having hidden properties," Elizabeth Gibney reports for *Nature.*

"Instead, the coordinated outcomes seem to be the result of measurements on one particle mysteriously fixing the properties of the other."

But scientists soon realised that there was a limit even to Bell's own limit - certain 'loopholes' that left open the possibility of non-quantum explanations.

One of these loopholes was that perhaps the particles were sharing information at the speed of light, and our instruments were too slow to pick up on this. Or perhaps the fact that experiments involving quantum entangled particles end up losing a bunch of them skewed the final results.

These two loopholes were finally addressed in 2015, when an "historic" experiment saw quantum entanglement pass its toughest test yet by discounting both possibilities as being more likely than quantum spookiness.

But one loophole remains - the freedom-of-choice loophole.

As Gibney explains, every time we use the Bell test, we assume that the scientists running the experiment have free choice over which measurements they perform on each of the pair of entangled photons (light particles):

> "But some unknown effect could be influencing both the particles and what tests are performed (either by affecting choice of measurement directly, or more plausibly, by restricting the options that are available), to produce correlations that give the illusion of entanglement."

In other words, imagine the Universe as a restaurant with 10 menu items.

"You think you can order any of the 10, but then they tell you, 'We're out of chicken,' and it turns out only five of the things are really on the menu," one of the team, Andrew Friedman from MIT, told *Quanta Magazine.*

"You still have the freedom to choose from the remaining five, but you were overcounting your degrees of freedom."

So when it comes to quantum entanglement experiments, "there might be unknowns, constraints, boundary conditions, conservation laws that could end up limiting your choices in a very subtle way", says Friedman, and these factors might fool us into thinking quantum entanglement is a thing.

One of the most obvious culprits in this scenario is gravity - perhaps its influence is limiting the number of possible measurements that we can make on entangled particles in Earth-based experiments.

So how do we get around the freedom-of-choice loophole when the universe itself seems to be against us?

"We outsource the choice to the Universe itself," Friedman told *Nature.*

In the past, researchers have tried to overcome the loophole by using a random number generator to randomly select which properties to measure, which means the researchers aren't introducing bias to the experiment by selecting the properties themselves.

They fire a pair of quantum particles in opposite directions towards two different detectors, and this random number generator picks the properties to measure at the very last moment before the particles arrive at their detectors.

This means the particles barely have any time to share information with each other and only appear to be entangled, as Einstein suspected.

The experiment was solid, but it only ruled out the influence of hidden variables several microseconds before the particles were fired.

What if things had been pre-determined before that?

A team involving researchers from MIT, the University of Vienna in Austria, and institutions in China and Germany, decided to use starlight as a way of pushing back the length of time where hidden influences could be discounted.

The experiment involved allocating the colour red or blue to certain properties that could be measured in entangled particles. Two telescopes were then set up to detect incoming starlight as either blue or red, and whichever colour was detected determined the properties that were to be measured in the entangled particles.

And here's the trick - because the colour of starlight cannot be changed along the way, it means if any hidden, non-quantum variables are messing with the particles and pre-determining the properties, it would have to be done before the starlight was emitted.

And seeing as the closest star to Earth (not including our Sun) investigated in the sample is 575 light-years away, it means this pre-determination would have to have been set in motion at least around 600 years ago.

"If any physical mechanism were to somehow jigger with the questions that get asked of each particle, those would have to have been put in motion at that star when it was about to emit that light that we measured," Kaiser told Leah Crane at *New Scientist.*

The experiment doesn't close the freedom-of-choice loophole altogether, but for the first time confirms that quantum spookiness has existed for at least the past 600 years, and now researchers have to figure out how to push this limit back even further.

Friedman thinks they can do this by applying the same technique to entangled particles using light from distant quasars. This should push the limit back billions of years, he says.

But what's the end game? The beginning of the Universe, i.e., the Big Bang?

That's not exactly something physicists are keen on confirming either, as Natalie Wolchover explains for *Quanta:*

> "It could be that the Universe restricted freedom of choice from the very beginning - that every measurement was predetermined by correlations established at the Big Bang.
>
> 'Superdeterminism', as this is called, is 'unknowable', said Jan-Åke Larsson, a physicist at Linköping University in Sweden; the cosmic Bell test crew will never be able to rule out correlations that existed before there were stars, quasars or any other light in the sky. That means the freedom-of-choice loophole can never be completely shut."

For Freidman, though, the possibilities are too intriguing not to chase.

"For us it seems like kind of a win-win," he told Wolchover. "Either we close the loophole more and more, and we're more confident in quantum theory, or we see something that could point toward new physics."

The study has been published in *Physical Review Letters.*