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Beyond black holes

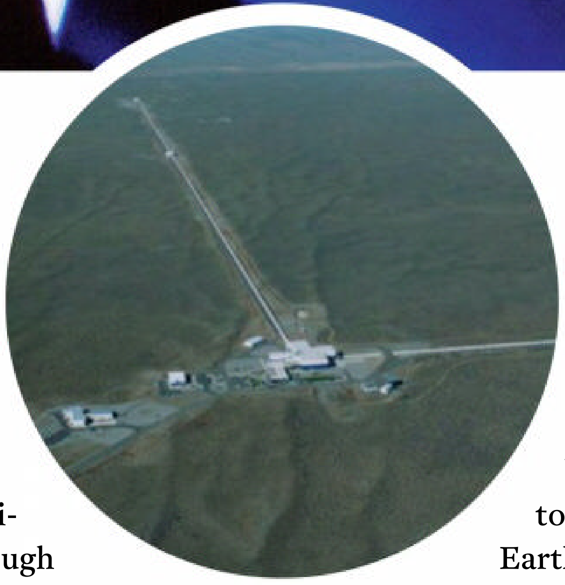
The detection of gravitational waves has opened the door to a new realm of cosmological discovery, says **David McClelland.**

I have a clear memory of the moment I knew I wanted to become a scientist – it was when Neil Armstrong stood on the Moon, in 1969. I was in my first year at high school in Perth, and watching that event was just inspirational. Right then I knew I wanted to try and understand more about the universe.

That was an event that stopped the world. And I think we experienced something similar when gravitational waves were detected in 2015. That discovery really captured the imagination of the general public. It was wonderful to be a part of it.

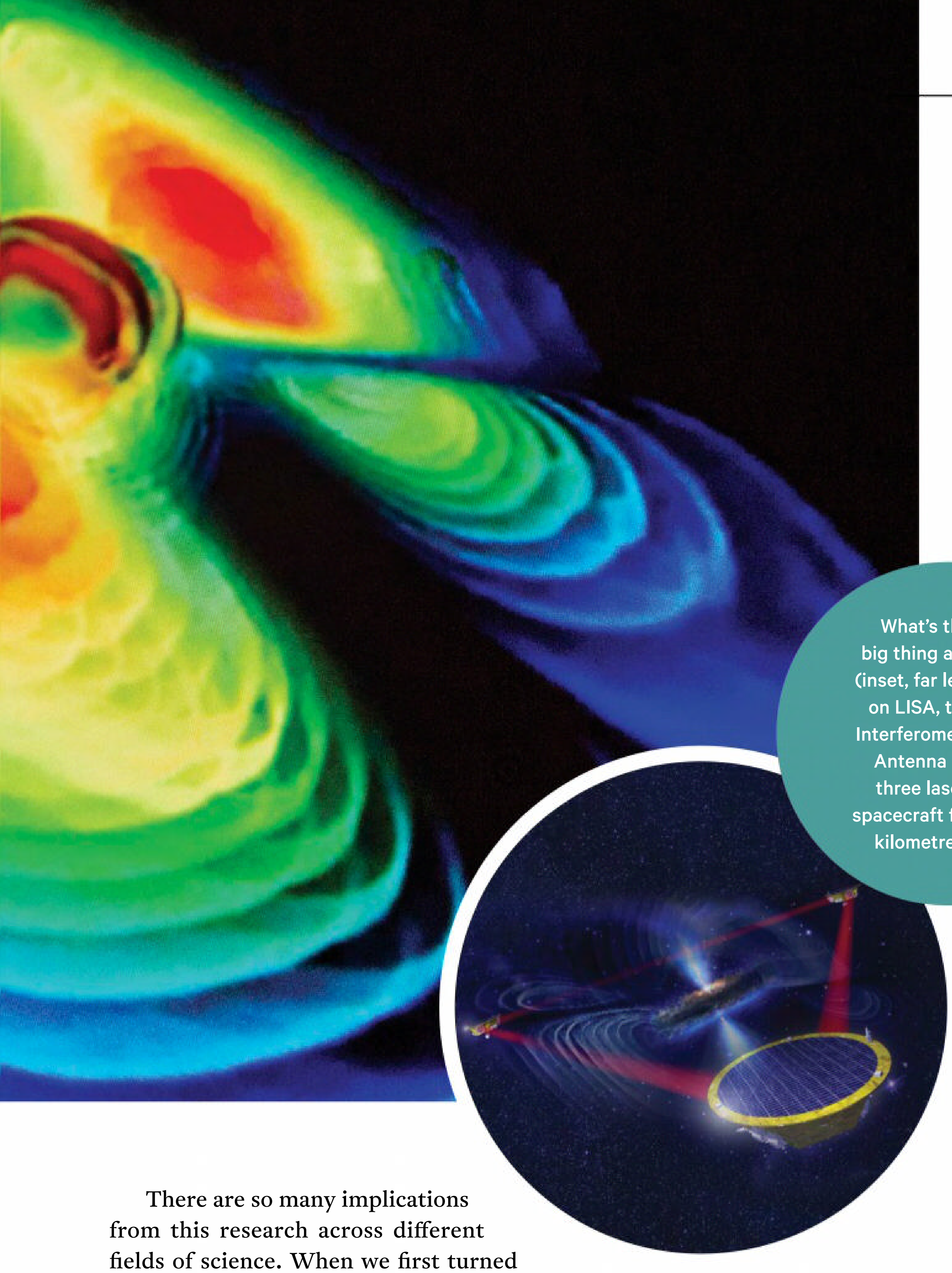
LIGO – our Laser Interferometer Gravitational-Wave Observatory in the US – was an enormous project. There were over 1,100 scientists involved and four major countries, and Australia was one of the partners. My team's role was to help understand how to make this interferometer work.

So, what's an interferometer? What we do is take a laser beam, split it in two, and send it down perpendicular arms, each four kilometres long. It then hits mirrors, and reflects back to where it was in the first place. And we measure how long it took the laser beam to go down one arm compared to how long it took to go down the other arm. If a gravitational wave passes through our interferometer, that timing is different.



Gravitational waves are ripples in spacetime, causing objects to stretch and squeeze as they move through. As a gravitational wave passes through the laser, it's squeezed in one direction and stretched in the other. So with these two perpendicular arms, one arm will be stretched – with the gravitational wave passing through getting a bit longer – and the other one will shrink, getting a bit shorter. We use interference to make that measurement. But even from gravitational waves generated in the most energetic events, that change is incredibly small – 10,000 times smaller than the size of a proton. So you have to build very big devices to measure extremely small effects. And we have to make those very big devices immune to all sorts of things on Earth that could disturb the positions of the mirrors – we only want the mirrors to be affected by the gravitational wave, so we have to put them in big vacuum systems and isolate them from Earthly disturbances. We have to make sure that the light we use is perfectly quiet as well; we don't want the light to be fluctuating, as that would disturb our measurement. A key part of our contribution was to reduce this, even below quantum limits. We then need to be able to control this distance measurement, one arm compared to the other. That's another area in which the Australian National University was heavily involved – we worked out a system that controls the mirrors.

FROM FAR LET: ANU; JULIAN STRATENSCHULTE / GETTY IMAGES; LIGO HANDFORD; EADS ASTRIUM.



What's the next big thing after LIGO (inset, far left)? Bring on LISA, the Laser Interferometer Space Antenna (below): three laser firing spacecraft five million kilometres apart.

There are so many implications from this research across different fields of science. When we first turned the detectors on, we not only learned that Einstein was right – we observed something we hadn't predicted. And that was two black holes of about 30 solar masses spiralling around each other and crashing together. That was what caused the gravitational wave that we measured. We didn't expect there to be black holes of that type of mass. We hadn't actually thought about that being the very first signal we would see, so it was quite serendipitous that this first signal was from an event that we hadn't actually expected. We've since discovered that there are a whole range of black holes of different masses that spiral around each other – black holes of masses that we hadn't predicted from any previous observations of astronomy. We're now trying to understand where they came from and how they formed. We know they come from massive stars – but we don't yet understand the process that produced 30 to 100 solar-mass black holes.

So we proved relativity, and we found this brand new signal – a signal which only comprises gravitational waves. It doesn't emit light. Everything we understood about the universe up until then had been from the light given off – the optical light, or radio, X-rays, gamma rays. But black hole collisions don't emit light.

My big excitement for the future is learning what else is out there in the dark side of the universe, just waiting to be discovered by these massive detectors.

It could be something like wormholes. Wormholes are fascinating. A black hole is something which just ends in a singularity – space and time cease. But a wormhole potentially connects to another part of the universe, and it could give off a different gravitational wave signal. They're still pure science fiction, but they exist in theory in general relativity.

There could also be cosmic strings – these are very long strings of gravitational energy which might be the seeds around which galaxies form. These cosmic strings might have a tension in them, and they could give off gravitational waves when they release that tension. We haven't seen any of those yet.

We're hoping that one day we will see gravitational waves from the very beginning of the universe. We know that there's a stochastic background out there, called the microwave background, that is pervasive throughout the universe. Again, it's not optical radiation. And we know that this "microwave background" was formed when the universe was about 300,000 years old. So that's as far back in time as we have currently been able to look. But from the gravitational waves background, we can learn about the universe less than a second after the Big Bang. So we'd be learning about the nuclear physics and the particle physics that happens in this enormously energetic event at the beginning of time.

Many such discoveries will require a global array of detectors, featuring a full-scale future-generation interferometer in Australia. We call the pathfinder for this detector NEMO – the Neutron star and Extreme Matter Observatory. After this, the next big thing might be the LISA project. It's very exciting – that's the Laser Interferometer Space Antenna. LISA is a bit like LIGO but it's in space. Instead of the mirrors being four kilometres apart, LISA will use three spacecraft in formation flying five million kilometres apart. Each spacecraft fires laser beams that are received by the other spacecraft. LISA will discover a new raft of sources that emit gravitational waves at lower frequencies than those observed by LIGO. That's something in which Australia is becoming more involved now.

There's a whole lot of interest in our gravitational wave detectors because we're beginning to understand how the most massive objects behave, discover objects on the dark side of the universe, and understand the fundamental forces in nature. ◉

As the lead Australian investigator in LIGO, **PROFESSOR DAVID McCLELLAND** has done work that has significantly expanded our view of the universe.