ATHANASSIOS KALIUDIS

# Rediscovering the universe with gravitational waves

**Gravitational waves can be used to find out things about the universe that humanity has not yet had access to. Aidan Brooks measures such gravitational waves - and expects big surprises.**

**Detecting gravitational waves has always required a huge effort and involved tremendous costs. Is it worth it?**

I would say yes, without a doubt! The first detection of gravitational waves in 2015 was a beautiful signal in its own right. One of my friends even had the signal tattooed onto his arm. But the important thing is that we're experiencing the start of an entirely new field of astronomy – one unlike anything we've seen before. It's also worth remembering that relative to other Big Science projects, the cost of the Laser Interferometer Gravitational-Wave Observatory, or LIGO, is quite modest. The International Thermonuclear Experimental Reactor (ITER) and the Large Hadron Collider (LHC), for example, cost over ten billion dollars each. LIGO only cost 1.2 billion dollars, spread over almost 30 years.

**So what do we get for those 1.2 billion dollars?**

We can now start to use gravitational waves to probe high-energy physics regimes that we've never had access to before, such as mergers of black holes or neutron stars. And when you combine that with electromagnetic observations of the universe to create multi-messenger astronomy, the science becomes even richer.

**What do you hope to learn from this research?**

There's a lot of science to be gained from examining the collisions of neutron stars. The pressures and densities of these events are far beyond what we can achieve on Earth. Gravitational waves give us a laboratory to explore physics beyond anything we could hope to achieve on our own planet. Of course, we still want to explore binary black hole systems and their population in the universe. And the question we're asking ourselves is whether there are dark matter candidates lurking in our gravitational wave signals. Could we be on the verge of discovering something completely unexpected? Something beyond anything we've imagined?

**What do you mean by that?**

It seems to be a universal law in science that brand-new technologies inevitably bring new surprises in terms of our understanding of the universe. And it's a relatively safe bet to say that gravitational waves are going to reveal plenty of surprises, both big and small. We've barely scratched the surface yet.

**In 2017 you detected gravitational waves from a merger of neutron stars 130 million light years away. Can you describe how it feels to arrive at work one day and suddenly experience something like that?**

"Sudden" is exactly the right way to describe it. There's no warning. You think you're having a normal day and then "bang!" – suddenly there's a signal alert. On that day, I had just arrived at the office. I made myself a coffee and planned, as usual, to check our event database which is normally just a long list of glitches. But suddenly my colleague rushed in and said there was something totally new in there. The signal was at least 20 seconds long – very different to anything we had seen before. At the same time, satellites had detected a large burst of gamma rays. We were all on a massive high for the next 24 hours, but then the news got even better: Our electromagnetic telescope partners had used our rough localization and found the exact source in the sky – a bright new object that hadn't been there days beforehand. Seventy telescopes turned to look at that object – all because of our signal! It was an exhilarating feeling.

Dr. Aidan Brooks is Senior Staff Scientist at the LIGO Laboratory at Caltech— the California Institute of Technology.



Each day, researchers filter out thousands of interfering signals for the highly sensitive laser interferometer — including their own footsteps.



**When you look at the curves on your monitor, how do you know what you're actually seeing? The observation of gravitational waves is such an indirect science. Doesn't that make you uneasy?**

From a human and emotional perspective, sure. But as scientists we're trained to trust our mathematics. The fact that we can trust our math is key to everything we do – especially when operating far beyond human scales.

**In addition to all the math, what are the essential requirements for detecting gravitational waves?**

There's a long list of things you need, but the decisive factor is always stability. Let me give you an example. When the detector – a laser interferometer – is at full power, it has nearly one million watts circulating inside it. Even though we have mirrors with extremely low absorption – less than one photon in every million –, the power absorbed by the mirrors still comes to a few hundred milliwatts. The pressure from the photons and the thermal expansion of the glass create very weak lens effects in our optics. When I say weak, I mean a focal length of tens of kilometers, but it's still enough to create major problems for our detectors!

**How do you counter that problem?**

We project CO2 laser beams onto the optics. The beams are precisely shaped to create a negative lens and remove this timedependent distortion in the optics. It’s extremely important that our CO2 lasers are perfectly stable. Believe it or not, large enough fluctuations in the CO2 laser power can show up as a dominant displacement noise source despite being of the order of one billionth of a billionth of a meter!

**What are the next steps in the LIGO project?**

Our primary goal is to improve the sensitivity of our detector. If we double our sensitivity, we increase the volume of events we can observe by a factor of eight. Right now, we’re working on squeezing quantum vacuum fluctuations. And we’re always hunting noise. We are also proposing a project to come online around 2024 called A+ which will involve some even cooler new squeezing technology and state-of-the-art coatings on the mirrors. With all that in place, we could be detecting one or more gravitational wave signals per day!

**You’ve been working for LIGO for over ten years. Up until 2015, you knew that the likelihood of detecting a gravitational wave was extremely low. How did it feel to spend years working on a goal with so little chance of success?**

I certainly wouldn’t characterize the likelihood of success as low, especially after the major sensitivity upgrade of LIGO into Advanced LIGO in 2015. I admit that the project was hugely daring and ambitious, but it wasn’t a pure gamble – it was based on solid science. With Advanced LIGO, we knew that there was a strong chance of detecting gravitational waves – so much so that we would have to review our understanding of General Relativity if we hadn’t seen anything. Again, we had to trust our mathematics. Our sponsor, the U.S. National Science Foundation, could see that if the project was successful, it had the potential to revolutionize physics and astronomy. And, following our first major upgrade, we were fortunate enough to detect something after only a few days. Things happened so fast that we didn’t have time to worry about not seeing any signals.

**Do you ever look at the stars at night?**

I live in Los Angeles, so the stars are never really visible. That said, when I’m at either of the detectors I occasionally take advantage of the opportunity to gaze at the stars. I have to admit, though, that I’d probably need an astronomy app to point to the location where our gravitational waves came from.

ATHANASSIOS KALIUDIS