SUSAN SCOTT PRESS RELEASE

LVK 10TH ANNIVERSARY FORT COLLINS USA

Ten years on, LIGO detecting black holes is almost like having your daily coffee

Today we celebrate the 10^{th} anniversary of the first direct detection of gravitational waves by the LIGO-Virgo collaboration. Gravitational waves are ripples in the fabric of space-time emanated by very dense objects in the universe moving at appreciable fractions of the speed of light. Einstein realised that gravitational waves are a prediction of his remarkable general theory of relativity which he presented to the world in 1915. He also knew that these waves would have ridiculously small amplitude, and was resigned to the fact that we would never be able to detect them.

Following Einstein's death in 1955 technology developed apace, and gravitational wave detection eventually entered the realm of possibility. In the early 1990s the twin LIGO gravitational wave detectors began construction in the United States, and over the following two decades the Centre for Gravitational Astrophysics (CGA) at the ANU played a significant role in designing and building instrumentation for these nascent observatories, and slowly but surely making them more sensitive to ultra-weak gravitational waves. The CGA was also a major contributor to the LIGO Data Analysis System and is a key developer of gravitational wave data analysis techniques and different types of searches for gravitational waves.

On the evening of 14 September 2015, Distinguished Professor Susan Scott – Leader of CGA theory and gravitational wave data analysis and Chief Investigator of OzGrav – was at home in Canberra, Australia. She recalls "around 9.30 pm I received a text message from my daughter saying that Australia had a new Prime Minister (Malcolm Turnbull had ousted Tony Abbott). I was focussed on that when an email came in saying "there has been a very interesting event in the LIGO detectors in the last hour". I forgot about the new Prime Minister and was glued to my computer as the story unfolded over the next few hours. It was so exciting that I didn't sleep a wink that night, just like when I was a kid going to bed on Christmas Eve!"

In one of the most spectacular breakthroughs ever achieved in physics, LIGO had detected the minute gravitational waves that rippled out from two black holes spiralling together and colliding somewhere in the distant universe. The waves had travelled for around 1.3 billion years at light speed before reaching Earth. To appreciate the extraordinary technical achievement of this detection, we need to realise that it was necessary to measure a change in length of the detector arms (LIGO is a capital L shape with 2 “arms” of length 4 km) of less than 1/10,000 the width of a proton!

This was also the first observation of a binary black hole merger and the first direct confirmation of Einstein’s theory of general relativity in what scientists call the “strong gravity regime” – regions of the universe with immensely stronger gravity than what we experience in our Solar System. Until this moment we had been observing the universe purely with signals from the electromagnetic spectrum, including light, radio waves and X-rays. Gravitational waves are not part of this spectrum and carry different information about the cosmos. An entirely new window onto the universe had been opened!

Fast forward ten years, and gravitational wave scientists from the LIGO-Virgo-KAGRA (LVK) Collaboration are gathered in Fort Collins, Colorado. But this is no ordinary collaboration meeting, since in addition to discussing the latest science, they will also celebrate the 10th anniversary of the detection of gravitational waves! They will be joined by international lead artist Benjamin Skepper, an Australian musician-artist-composer, who will perform the world premiere of his latest work WAVES! This composition draws directly from raw gravitational wave data collected by LIGO, translating black hole collisions and neutron star mergers into a richly spatialised immersive soundscape. Skepper, who collaborates with Professor Scott, says “art provides a vehicle to translate complex science into experiences people can feel, a vital form of public engagement”.

In the last decade the LVK Collaboration has detected around 300 binary black hole collisions as well as, importantly, a handful of binary neutron star and black hole – neutron star mergers. Professor Scott says “we have learnt so much about the deaths of stars and the lives of black holes, including the celestial environments in which stars die to create black holes and form binaries, the spin of black holes, the shape of the orbits of these binary systems, and the presence of very light black holes as well as intermediate mass black holes”. With the constantly improving sensitivity of the gravitational wave detectors, detection rates have increased from 3 detections in the first four-month Observing Run in 2015-2016, to currently, in the fourth Observing Run, registering a binary black hole merger roughly once every three days! According to Scott “these days having a binary black hole coalescence pop up on my phone is almost like having my daily coffee; both are always highlights of the day!”

The LVK Collaboration also announces the best observational evidence yet for the black hole area theorem; a central law for black hole physics proposed by Stephen Hawking in 1971 predicting that the total area of black hole event horizons - the one-way membranes beyond which nothing can escape – can never shrink. In a new study just published in the *Physical Review Letters*, with data obtained from the binary black hole merger detected on 14 January this year, the team determined that the original spiralling black holes had a total surface area of 240,000 square kms (slightly more than the area of Victoria, Australia), while the newly formed black hole's surface area was about 400,000 square kms (about half the area of New South Wales, Australia). This is a clear increase, providing strong corroboratory support for Hawking's theorem.

When two black holes merge, the resultant black hole vibrates like a struck bell, called the ringdown phase of the signal. With this event, the team were able to precisely measure the details of the ringdown phase, the trickiest part of this type of analysis, enabling a calculation of the mass and spin of the final black hole leading to a determination of its surface area. "Excited black holes are known to 'ring' like cosmic bells at precise frequencies. This is the strongest and cleanest black hole 'note' we've ever heard" said Neil Lu, a PhD student in the CGA who works on this project and is a member of OzGrav. "For the first time, we can clearly identify more than one of the predicted tones from the final black hole, and they match exactly what Einstein's theory says they should."

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