Evincing the histories of the cosmic supermassive black hole and galaxy populations with gravitational waves

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Our Universe is incredibly dynamic. Within our Galaxy, small stars known as pulsars spin as fast as once every millisecond, emitting intense beams of radio waves that sweep by the Earth. Galaxies themselves crash into each other; indeed, large galaxies like our own are likely to have formed from the constant accumulation of smaller galaxies. At the centre of each galaxy lies a black hole: objects so dense that even light cannot travel fast enough to escape their gravity. Some of these black holes hoard material weighing more than ten billion times the Sun within a region the size of the Solar System. But, when two galaxies merge, what happens to the black holes? This question formed the basis of my PhD research. Calculations have shown that the black holes in two merging galaxies should fall to the centre of the newly formed galaxy, and start to orbit one another. The dance quickly turns deadly, as the orbiting black holes emit gravitational waves: stretches and compressions of space itself. This SIEF John Stocker Postgraduate Scholarship – Final Report causes them to spiral closer and closer to each other, and to eventually collide to form a new, bigger black hole. Whether this occurs is unknown. Gravitational waves, a key prediction of Einstein's general relativity, have themselves never been detected. However, if present, gravitational waves will affect the apparent rotations of pulsars in our Galaxy, which can be monitored by recording the radio beeps observed as their emission beams sweep by the Earth. The world-leading Parkes Pulsar Timing Array collaboration has been using the CSIRO Parkes radio telescope in rural NSW ("the Dish") to monitor 20 of the most stably rotating pulsars in our Galaxy over the last decade. The goal of my PhD was to model the gravitational wave signals from pairs of black holes, and to then search for these signals in the pulsar data. Using a large computer-generated simulation of the galaxy and black hole populations of the Universe, I showed that pairs of black holes should also interact with their environments, hastening their collisions but weakening the expected gravitational wave signal. Nonetheless, I found that gravitational waves from rare nearby pairs of black holes, as well as a background signal from millions of more distant systems, should be detectable in pulsar data. However, no hints of gravitational waves were evident in the data. This was remarkable, because a popular model where all galaxy evolution in the last 8 billion years of the history of the Universe was driven by galaxy mergers predicted a large population of black hole pairs, with detectable gravitational waves. Clearly, this scenario was incorrect. I concluded that other processes besides mergers drove galaxy and black hole growth. In 2013, this result was published in the prestigious journal Science. My PhD project represented the first time that a gravitational-wave study resulted in meaningful insights into the Universe. Gravitational wave science is among the hottest topics in modern astrophysics, and a key motivator of the international Square Kilometre Array radio telescope to be built in Western Australia. For the moment, the Parkes Pulsar Timing Array collaboration will continue to monitor pulsars, now with a clear knowledge of what to look for, and will continue to provide unique insights into black hole and galaxy evolution.