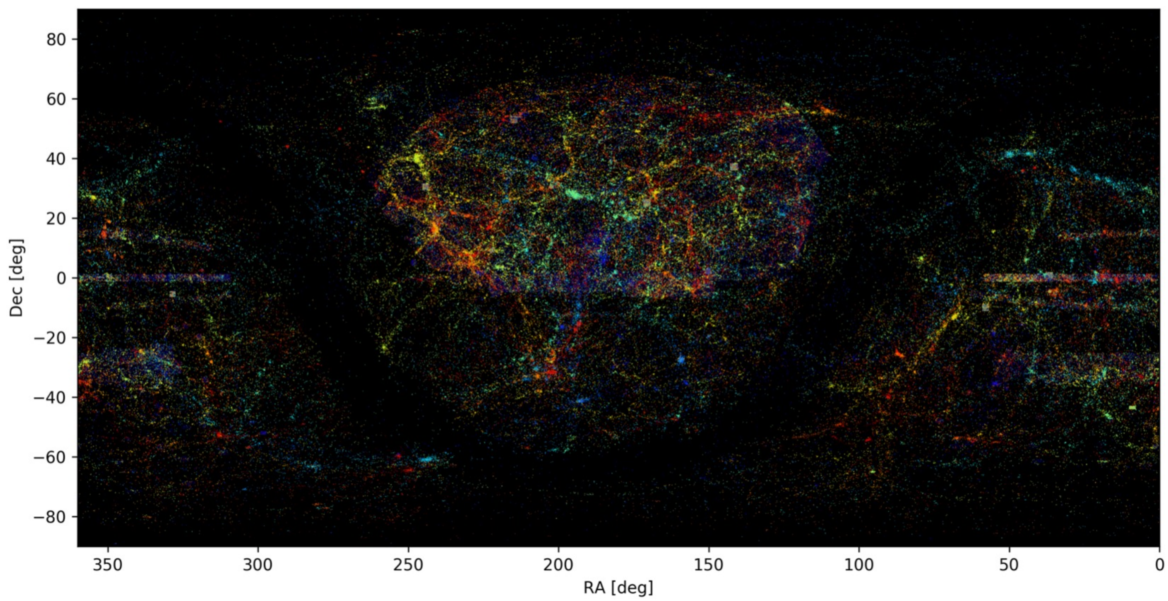
Finding the Source of Gravitational Waves in the First Five Minutes: *HotShots* Citizen Science Project

Ann Zabludoff + The *HotShots* Collaboration

In 2017, for the first time, gravitational waves *and* light were detected from the same source—GW170817—a violent collision of two neutron stars. That discovery was made using the U.S.-based Laser Interferometer Gravitational-Wave Observatory (LIGO), the Europe-based Virgo detector, and over 70 ground- and space-based observatories world-wide. It ushered in the era of "multi-messenger astrophysics," where light, particles, and gravitational radiation are analyzed together.

GW170817 was seen immediately as a gamma-ray burst by the *Fermi* spacecraft. Observatories around the world then started searching the sky where the gravitational waves and gamma rays were thought to originate. Eleven hours later, a new point of light in a galaxy was found by optical telescopes. Detections at other wavelengths soon followed.

Theoretical models predict that colliding neutron stars generate gravitational waves and gamma rays. When two massive, accelerating bodies spiral together, they stretch and distort space-time nearby, producing powerful gravitational waves. The merger produces a fireball of gamma radiation. The detection of both gravitational waves and gamma rays at Earth confirmed General Relativity, which predicts that gravitational waves travel at light speed. The subsequent detection of optical light was likely the glow from the radiative decay of nuclei left over and flung out from the collision; this "kilonova" showed that elements such as platinum and gold are created and widely dispersed by neutron star collisions.



Sky distribution of about 300K bright galaxies that could potentially host gravitational wave (GW) events (Yujing Qin 2019). For each GW alert, about 50 to several hundred of these galaxies will have locations and distances consistent with the GW source; all those galaxies will be targeted in parallel by citizen observers.

While telescopes everywhere observed the kilonova for months, revealing more about how the collision altered its surroundings and generated heavy elements, the long delay between the alert and optical detection prevented measurements during the early brightening phase, a short period critical for testing physics. This delay arose from the difficulties in localizing the gravitational wave detection on the sky. *A new discovery space would open if the localization time could be reduced to the first minutes after the alert.*

We propose a collaboration with citizen scientists to rapidly discover new gravitational wave events in optical light. Our plan is to crowd-source the detection to *within the first five minutes of the gravitational wave alert*. Instead of observing possible host galaxies one-by-one or imaging wide-regions of the sky with poor spatial resolution, our collaboration will target the galaxies in parallel.

Citizen observers world-wide can express their interest via our **hotshots** website. At the time of the alert, we will send each observer an accessible galaxy target, selected from those most likely to host the merged neutron star binary. We will provide a galaxy image taken from before the gravitational wave event and adjusted to the observer's filter and field-of-view. We enclose a link for the observer to indicate whether or not there is a new star in or near the galaxy. Even those who observe robotically will have the option of auto-uploading their images so that others may search for changes. If they discover the gravitational wave source, they receive credit in the scientific literature!