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Gold factories in the Universe

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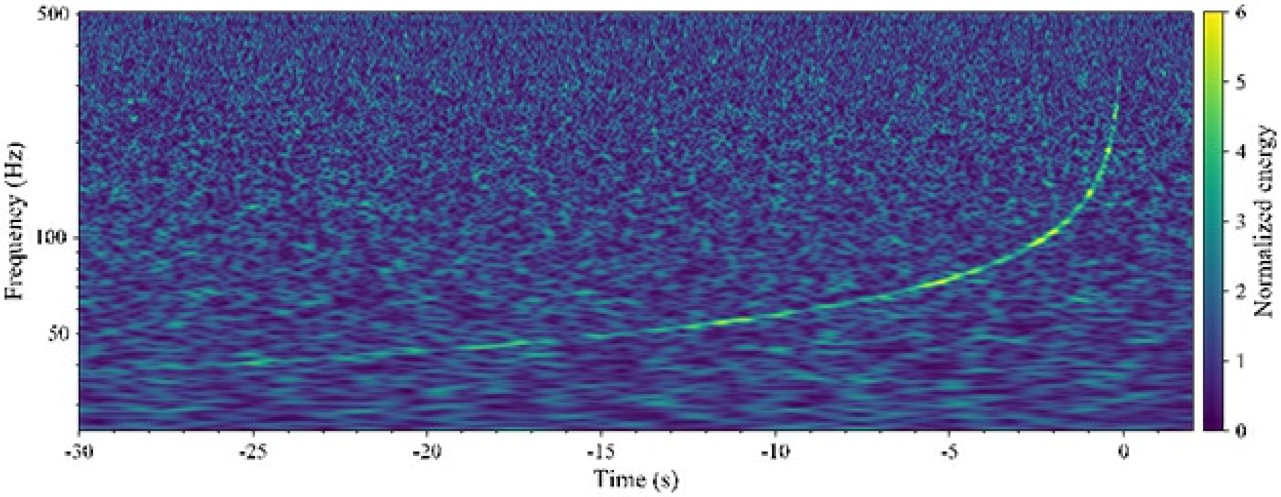
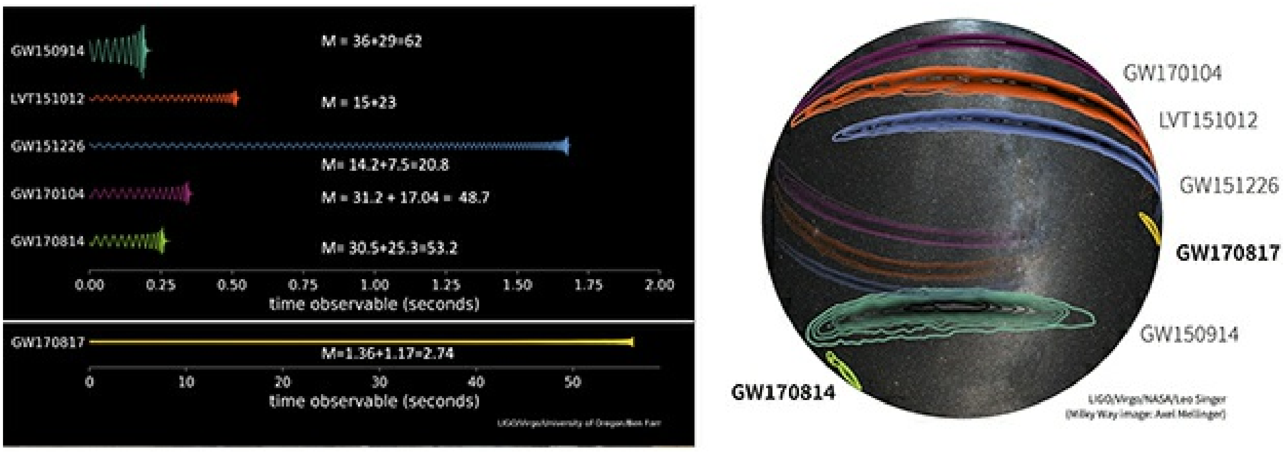


The first neutron star binary inspiral detected by the Gravitational Wave Detection Network. (Credit Alexander Nitz, Max Planck Institute for Gravitational Physics, Albert Einstein Institute). Also watch the animated spectrogram with audio.

In August 2017 the Gravitational Wave Detection Network, comprised of Advanced Virgo and the two Advanced LIGO observatories, was listening for gravitational wave (GW) events before it shut down again for refinements to further improve its sensitivity. The operation in coincidence of the three detectors allowed, for the first time, triangulation in the sky and good directionality for the detected events. During this brief window of time several interesting events were detected, including at least one from black hole (BH-BH) inspiral and merger and one from neutron stars (NS-NS), and directionality was important! The glimpse through this newly opened window on the cosmos showed us an exciting landscape and generated many new questions. We are now in an active Q&A with the Universe.



The detection of 5 BH-BH and 1 NS-NS inspirals (compared waveform). The last two August events, GW170814 and GW170817, have better directionality due to the triangulation allowed by the three-observatory detection mode. Surprisingly, almost all of the BHs are of a heavier mass than expected for stellar BHs. They enter the detection band and complete their inspiral in about a second or less. The NS-NS inspiral lasted almost a minute. (Credit Ben Farr, University of Oregon and Leo Singer, NASA Goddard Space Flight Center). Also watch the animated localization in the sky.

Where do stellar BHs come from? It is believed that the BH masses detected by Virgo and LIGO cannot be produced in the present high-metallicity galaxies (i.e. with high concentrations of elements heavier than helium), as stellar wind would be expected to blow out too much mass before they finish burning and collapse. Could the low-metallicity era that is the hallmark of the early Universe have lasted longer and produced more BHs before stellar nucleosynthesis and supernovae seeded the galactic gas with higher metallicity gas and made large BH formation impossible? Or are these BHs primordial, formed in the turbulence during the earliest moments after the Big Bang? Are there perhaps even enough of the BHs to explain the dark matter puzzle? What mechanism brings BHs to inspiral in times comparable with the age of the Universe? Is it the gravitational friction inside globular clusters that brings them together, or are there simply so many out there that the infinitesimal fraction that inspirals without friction is sufficient to justify the merger rate that we have observed? Or is it a completely different picture that we have not yet dreamt of?

If the BH-BH events are interesting, the single NS-NS event is even more shocking. The great news is that it was not only detected by the three GW observatories; ejecta and their decay were observed first in a short Gamma Ray Burst (GRB) and in the optical cooling curve of a kilonova located at the edge of a host galaxy exactly at the location pointed to by the gravitational wave signals! In one shot, the puzzle of short GRBs and the origin of kilonovae may have been solved.

There is more: the afterglow appears to contain the fluorescence of heavy metals. In recent years the puzzle of the production of metals heavier than iron has grown more and more troubling. Initially it was thought that the shock wave of a core-collapse supernova would be sufficient to synthesize heavy metals through rapid neutron capture processes (r-processes) that add one neutron at a time. New evaluations, however, suggest that the NS shock waves are insufficient to account for the observed abundances of heavy metals because they are too fast. As an alternative it was surmised that the r-processes synthesizing heavy metals may happen in the much more neutron-rich ejecta of NS-NS inspirals. The ejecta observed following this exciting new gravitational-wave event appear more than sufficient to justify the existing heavy metal concentrations.

The exciting view through our new window suggests that the Universe may be wilder than we think. Perhaps the Celtic legends that pots of gold lie at the end of rainbows have some truth. Perhaps the end of the frequency rainbow of NS-NS inspirals will bring us to the galactic gold factories that produced the heavy metals.

The new window that we’ve opened is so exciting and question-rich. Certainly many new theories will be generated even before the GW detectors come back online with the prospect of daily events in their next observing runs. Many of these theories will be tested and disproven, but some will survive to give us a better understanding of our Universe.

Currently, both Virgo and LIGO are still at ~30% or less of their design sensitivity. Once the detectors reach their design goal of three times the current sensitivity, they will be sensitive to a volume 27 times larger. At this point, daily or even more frequent GW events will be the norm, and GW astronomy will be in full swing.

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