Neutron star smashup seen for first time, 'transforms' understanding of Universe

16 October 2017, by Marlowe Hood

This artist's impression shows two tiny but very dense neutron stars at the point at which they merge and explode as a kilonova. Such a very rare event is expected to produce both gravitational waves and a short gamma-ray burst, both of which were observed on 17 August 2017 by LIGO-Virgo and Fermi/INTEGRAL respectively. Subsequent detailed observations with many ESO telescopes confirmed that this object, seen in the galaxy NGC 4993 about 130 million light-years from the Earth, is indeed a kilonova. Such objects are the main source of very heavy chemical elements, such as gold and platinum, in the Universe. Credit: ESO/L. Calçada/M. Kornmesser

For the first time, scientists have witnessed the cataclysmic crash of two ultra-dense neutron stars in a galaxy far away, and concluded that such impacts forged at least half the gold in the Universe.

Shockwaves and light flashes from the collision travelled some 130 million light-years to be captured by Earthly detectors on August 17, excited teams revealed at press conferences held around the globe on Monday as a dozen related science papers were published in top academic journals.

"We witnessed history unfolding in front of our eyes: two neutron stars drawing closer, closer... turning faster and faster around each other, then colliding and scattering debris all over the place," co-discoverer Benoit Mours of France's CNRS research institute told AFP.

The groundbreaking observation solved a number of physics riddles and sent ripples of excitement through the scientific community.

Most jaw-dropping for many, the data finally revealed where much of the gold, platinum, uranium, mercury and other heavy elements in the Universe came from.

Telescopes saw evidence of newly-forged material in the fallout, the teams said—a source long suspected, now confirmed.

"It makes it quite clear that a significant fraction, maybe half, maybe more, of the heavy elements in the Universe are actually produced by this kind of collision," said physicist Patrick Sutton, a member of the US-based Laser Interferometer Gravitational-Wave Observatory (LIGO) which contributed to the find.

Neutron stars are the condensed, burnt-out cores that remain when massive stars run out of fuel, blow up, and die.

Typically about 20 kilometres (12 miles) in diameter, but with more mass than the Sun, they are highly radioactive and ultra-dense—a handful of material from one weighs as much as Mount Everest.

An image of Swope Supernova Survey 2017a (or SSS17a) from the night of discovery. On August 17, a team of four Carnegie astronomers provided the first-ever glimpse of two neutron stars colliding, opening the door to a new era of astronomy. Credit: Tony Piro.

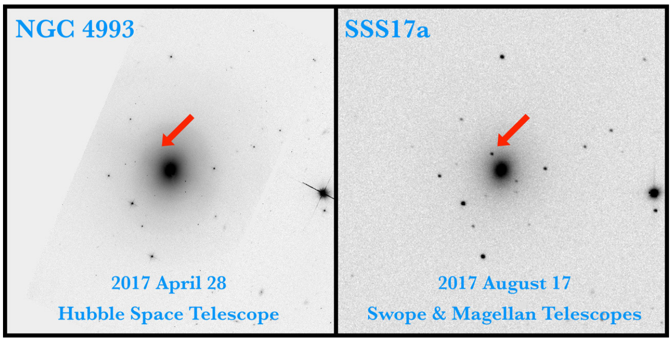
The observation was the fruit of years of labour by thousands of scientists at more than 70 ground- and space-based observatories on all continents.

Along with LIGO, they include teams from Europe's Virgo gravitational wave detector in Italy, and a number of ground- and space-based telescopes including NASA's Hubble.

"This event marks a turning point in observational astronomy and will lead to a treasure trove of scientific results," said Bangalore Sathyaprakash from Cardiff University's School of Physics and Astronomy, recalling "the most exciting of my scientific life."

"It is tremendously exciting to experience a rare event that transforms our understanding of the workings of the Universe," added France Cordova, director of the National Science Foundation which funds LIGO.

The detection is another feather in the cap for German physicist Albert Einstein, who first predicted gravitational waves more than 100 years ago.



The UC Santa Cruz team found SSS17a by comparing a new image of the galaxy N4993 (right) with images taken four months earlier by the Hubble Space Telescope (left). The arrows indicate where SSS17a was absent from the Hubble image and visible in the new image from the Swope Telescope. Credit: Image credits: Left, Hubble/STScI; Right, 1M2H Team/UC Santa Cruz & Carnegie Observatories/Ryan Foley

'Too beautiful'

It had been theorised that mergers of two such exotic bodies would create ripples in the fabric of space-time known as gravitational waves, as well as bright flashes of high-energy radiation called gamma ray bursts.

On August 17, detectors witnessed both phenomena, 1.7 seconds apart, coming from the same spot in the constellation of Hydra.

"It was clear to us within minutes that we had a binary neutron star detection," said David Shoemaker, another member of LIGO, which has detectors in Livingston, Louisiana and Hanford, Washington.

"The signals were much too beautiful to be anything but that," he told AFP.

Something 'fundamental'

Three LIGO pioneers, Barry Barish, Kip Thorne and Rainer Weiss, were awarded the Nobel Physics Prize this month for the observation of gravitational waves, without which the latest discovery would not have been possible.

The ripples have been observed four times before now—the first time by LIGO in September 2015. All four were from mergers of black holes, which are even more violent than neutron star crashes, but emit no light.

The fifth and latest detection was accompanied by a gamma ray burst which scientists said came from nearer in the Universe and was less bright than expected.

"What this event is telling us is that there may be many more of these short gamma ray bursts going off nearby in the Universe than we expected," Sutton said—an exciting prospect for scientists hoping to uncover further secrets of the Universe.

Among other things, it is hoped that data from neutron star collisions will allow the definitive calculation of the rate at which the cosmos is expanding, which in turn will tell us how old it is and how much matter it contains.

"With these observations we are not just learning what happens when neutron stars collide, we're also learning something fundamental about the nature of the Universe," said Julie McEnery of the Fermi gamma ray space telescope project.

Neutron star smash-up the 'discovery of a lifetime'

"Truly a eureka moment", "Everything I ever hoped for", "A dream come true"—Normally restrained scientists reached for the stars Monday to describe the feelings that accompany a "once-in-a-lifetime" event.

The trigger for this meteor shower of superlatives was the smash-up of two unimaginably dense neutron stars 130 million years ago.

Evidence of this cosmic clash hurtled through space and reached Earth on August 17 at exactly 12:41 GMT, setting in motion a secret, sleepless, weeks-long blitzkrieg of star-gazing and number-crunching involving hundreds of telescopes and thousands of astronomers and astrophysicists around the world.

It was as if a dormant network of super-spies simultaneously sprung into action.

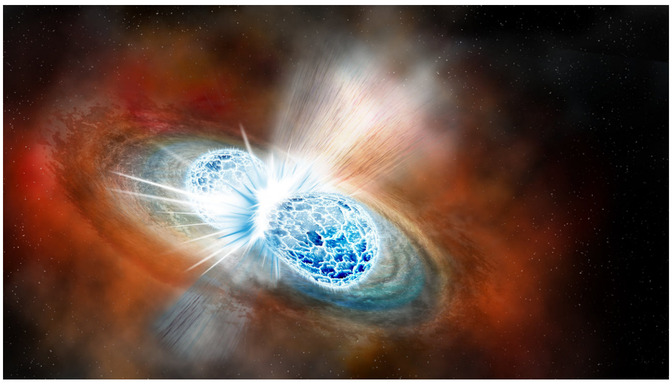
The stellar smash-up made itself known in two ways: it created ripples called gravitational waves in Einstein's time-space continuum, and lit up the entire electromagnetic spectrum of light, from gamma rays to radio waves.

Scientists had detected gravitational waves four times before, a feat acknowledged with a Nobel Physics Prize earlier this month.

But each of those events, generated by the collision of black holes, lasted just a few seconds, and remained invisible to Earth- and space-based telescopes.

The neutron star collision was different.

It generated gravitational waves—picked up by two US-based observatories known as LIGO, and another one in Italy called Virgo—that lasted an astounding 100 seconds. Less than two seconds later, a NASA satellite recorded a burst of gamma rays.



Artist's concept of the explosive collision of two neutron stars. Credit: Robin Dienel courtesy of the Carnegie

Institution for Science.

A true 'eureka' moment

This set off a mad dash to locate what was almost certainly the single source for both.

"It is the first time that we've observed a cataclysmic astrophysical event in both gravitational and electromagnetic waves," said LIGO executive director David Reitze, a professor at the California Institute of Technology (Caltech) in Pasadena

Initial calculations had narrowed the zone to a patch of sky in the southern hemisphere spanning five or six galaxies, but frustrated astronomers had to wait for nightfall to continue the search.

Finally, at around 2200 GMT, a telescope array in the northern desert of Chile nailed it: the stellar merger had taken place in a galaxy known as NGC 4993.

Stephen Smartt, who led observations for the European Space Observatory's New Technology Telescope, was gobsmacked when the spectrum lit up his screens. "I had never seen anything like it," he recalled.

Scientists everywhere were stunned.

"This event was truly a eureka moment," said Bangalore Sathyaprakash, head of the Gravitational Physics Group at Cardiff University. "The 12 hours that followed are inarguably the most exciting of my scientific life."

"There are rare occasions when a scientist has the chance to witness a new era at its beginning—this is one such time," said Elena Pian, an astronomer at the National Institute for Astrophysics in Rome.

LIGO-affiliated astronomers at Caltech had spent decades preparing for the off chance—calculated at 80,000-to-one odds—of witnessing a neutron star merger.

Don't tell your friends

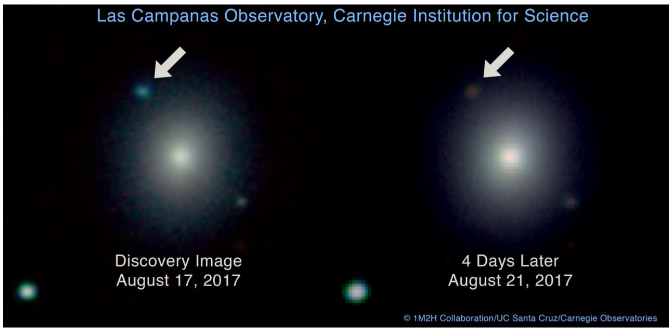
"On that morning, all of our dreams came true," said Alan Weinstein, head of astrophysical data analysis for LIGO at Caltech.

"This discovery was everything I always hoped for, packed into a single event," added Francesco Pannarale, an astrophysicist at Cardiff University in Wales.

For these and thousands of other scientists, GW170817—the neutron star burst's tag—will become a "do you remember where you were?" kind of moment.

"I was sitting in my dentist's chair when I got the text message," said Benoit Mours, an astrophysicist at France's National Centre for Research and the French coordinator for Virgo. "I jumped up and rushed to my lab."

Patrick Sutton, head of the gravitational physics group at Cardiff and a member of the LIGO team, was stuck on a long-haul bus, struggling to download hundreds of emails crowding his inbox.



A comparison of images of Swope Supernova Survey 2017a (or SSS17a) from the night of discovery, August 17, and four nights later, August 21. Credit: Tony Piro.

Rumours swirled within and beyond the astronomy community as scientists hastened to prepare initial findings for publication Monday in a dozen articles spread across several of the world's leading journals.

"There have been quite a few pints and glasses of wine or bubbly—privately, of course, because we haven't been allowed to tell anyone," Sutton told AFP.

But he couldn't resist telling his 12-year-old son, an aspiring physicist.

"He's sworn to secrecy though. He's not allowed to tell his friends."

LIGO and Virgo: The machines that unlock the universe's mysteries

The three machines that gave scientists their first-ever glimpse of gravitational waves resulting from a collision of neutron stars are the most advanced detectors ever built for sensing tiny vibrations in the universe.

The LIGO and Virgo detectors have previously picked up the "chirp" of black holes merging in the distant universe, sending out ripples in the fabric of space and time.

The detection of these gravitational waves for the first time in 2015 confirmed Albert Einstein's century old theory of general relativity.

The two US-based underground detectors are known as the Laser Interferometer Gravitational-wave Observatory, or LIGO for short.

One is located in Hanford, Washington; the other 1,800 miles (3,000 kilometers) away in Livingston, Louisiana.

Construction began in 1999, and observations were taken from 2001 to 2007.

Then they underwent a major upgrade to make them 10 times more powerful.

The advanced LIGO detectors became fully operational for the first time in September 2015.

On September 14, 2015, the detector in Louisiana first picked up the signal of a gravitational wave, originating 1.3 billion years ago in the southern sky.

Virgo

The third underground detector is near Pisa, Italy, and is known as Virgo.

Built a quarter century ago by a French-Italian partnership, the Virgo detector ended its initial round of observations in 2011 and then underwent an upgrade.

Advanced Virgo came online in April of this year, and made its first observation of gravitational waves on August 14, marking the fourth such event that scientists have observed since 2015.

Virgo is less sensitive than LIGO, but having three detectors helps scientists zero in on the area of the universe where a cosmic event is happening, and measure the distance with greater accuracy.

"A smaller search area enables follow-up observations with telescopes and satellites for cosmic events that produce gravitational waves and emissions of light, such as the collision of neutron stars," said Georgia Tech professor Laura Cadonati.

How they work

These huge laser interferometers—each about 2.5 miles (four kilometers) long—are buried beneath the ground to allow the most precise measurements.

The L-shaped instruments track gravitational waves using the physics of laser light and space.

They do not rely on light in the skies like a telescope does.

Rather, they sense the vibrations in space, an advantage which allows them to uncover the properties of black holes and neutron stars.

"As a gravitational wave propagates through space it stretches space-time," explained David Shoemaker, leader of the Advanced LIGO project at the Massachusetts Institute of Technology (MIT).

The detector, in short, "is just a big device for changing strain in space into an electrical signal."

One way to imagine the curvature of space and time is to imagine a ball falling on a trampoline.

The trampoline bows downward first, stretching the fabric vertically and shortening the sides.

Then as the ball bounces upward again, the horizontal movement of the fabric expands again.

The instrument acts like a transducer, changing that strain into changes in light—and then into an electronic signal so scientists can digitize it and analyze it.

"The light from the laser has to travel in a vacuum so that it is not disturbed by all the air fluctuations," said Shoemaker, noting that LIGO contains the "biggest high vacuum system in the world,"—measuring 1.2 meters (yards) by 2.5 miles (four kilometers) long.

The detectors contain two very long arms that contain optical instruments for bending light, and are positioned like the letter L.

If one arm shortens, and the other lengthens, scientists know they are seeing a gravitational wave.

Read more: What are neutron stars?

Read more: Gravitational waves: Why the fuss?

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