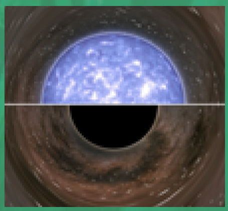
LSC LIGO Scientific Collaboration

issue 18 3/2021

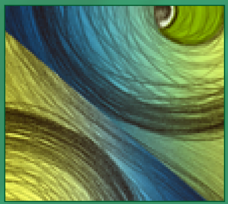
LIGO MAGAZINE

O4 commissioning
p.6



The O3a catalog: Apr 1 to Oct 1 2020

Half-time harvest of LIGO and Virgo's third observing run p.11



Art, music, and gravitational waves

When gravitational waves ripple across the arts world p.14

... and the importance of mental health and good supervision p.26

Front cover

Marie Kasprzack uses a green flashlight to inspect the surface of the ETMY optic at LIGO Livingston as part of the Observing Run 4 commissioning upgrades.

Top inset: Artistic representation of the less massive component in the merger producing GW190814, which could have been either the heaviest neutron star or the lightest black hole.

Bottom inset: “Music of the Spheres” by Charles Heasley (see also pp. 14-15).

Image credits

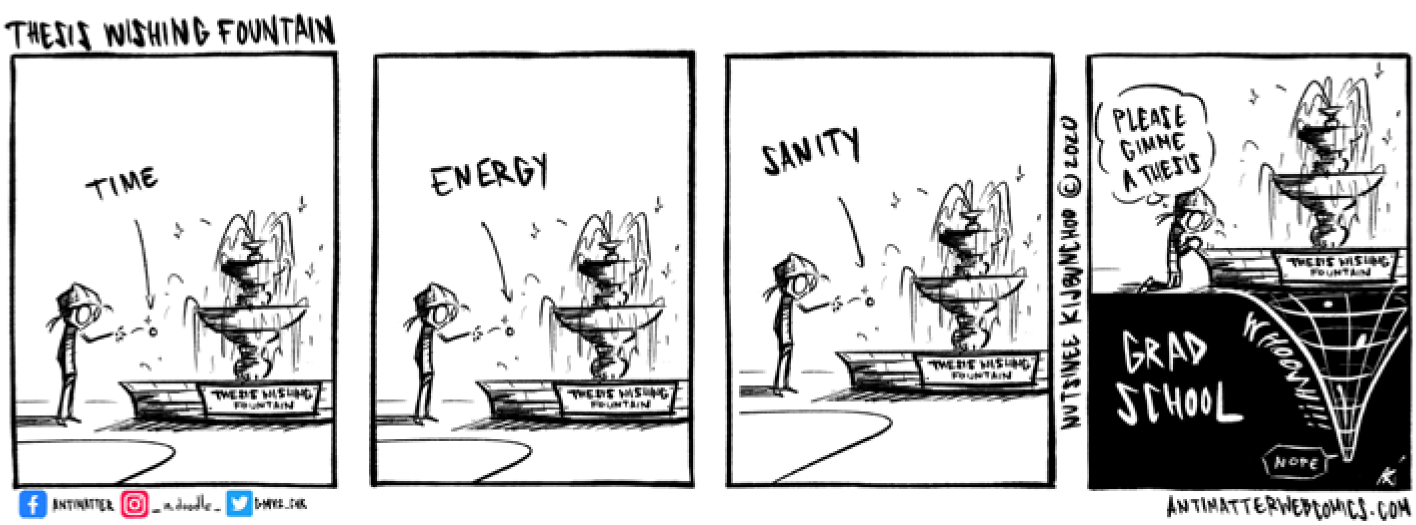
Photos and graphics appear courtesy of Caltech/MIT LIGO Laboratory and LIGO Scientific Collaboration unless otherwise noted.

Cover: Main image: Photo by Arnaud Pele. Top inset: LIGO/Caltech/MIT/R. Hurt (IPAC). Bottom inset: “Music of the Spheres” by Charles Heasley.

p. 3 Antimatter comic strip by Nutsinee Kijbunchoo.
pp. 6-10 Virgo infrastructure modifications photo by Carlo Fabozzi (p. 6); Virgo signal recycling mirror photo by Maurizio Perciball.
pp. 11-13 Artistic representation of GW190425 by Aurore Simonnet/LIGO/Caltech/MIT/Sonoma State (p. 11); Compact object masses graphic by LIGO-Virgo/Northwestern U./Frank Elavsky & Aaron Geller (p. 12); Artistic impression of GW190521 by Mark Myers, ARC Centre of Excellence for Gravitational Wave Discovery (OzGrav) (p. 13).
pp. 15-24 Music of the Spheres” by Charles Heasley (p. 14); Gravity Synth photo by Live Performers Meeting, Rome (p. 15); Sounds of GW150914 performance image from Nick Bannon (p. 16); Gravitational wave detector by Carl Knox, ARC Centre of Excellence for Gravitational Wave Discovery (OzGrav) (p. 17); Photo of Samaya Nissanke from the Breakthrough Prize Foundation (p. 17); Nobel laureate paintings by Nutsinee Kijbunchoo (p. 18); Portraits of LIGO by Laurence Datrier (p. 19); Scarf photo by Kelly Ricks (p. 19); LIGO DRT Station photos by JT Bullitt/Downeast Rapid Transit (p. 20); “Crystal gazing” by Riccardo Buscicchio, textures: chocofur.com (p. 20); Mirror restoration photo by Isabel Cordero Carrión (p. 21); Roundabouts in Richland sculpture photos by Rhiza A+D (p. 21); GW190425 by Aurore Simonnet/LIGO/Caltech/MIT/Sonoma State (p, 22); Photo of “Phase Evolution” by Anastasia Azure (p23); Congress of Astrophysics photo from The High Conservatory of Dance of Valencia (p. 23); Cosmic Whispers by Samanwaya Mukherjee/Kanchan Soni/Debarati Chatterjee/Gravity Matters (p. 24); “The New Wave” by Felicity Spear (p. 24).
p. 25 Gravity Matters graphic from LIGO India/Gravity Matters/Debarati Chatterjee with components: A. Einstein by F. Schmutzer; Merger simulation by D. J. Price and S. Rosswog, Science 312 (2006) 719, Virgo photo from Virgo; Jocelyn Read by CSUF Photos; Masses in the stellar graveyard by LIGO-Virgo/Northwestern U./Frank Elavsky & Aaron Geller; All other images by Debarati Chatterjee / IUCAA.
p. 26 Plots by Jessica Steinlecher with data from Evans, T., Bira, L., Gastelum, J. et al. “Evidence for a mental health crisis in graduate education.”, Nat. Biotechnol 36, 282–284 (2018). https://doi.org/10.1038/nbt.4089
p. 28 Dyson Spectrometer photograph by Craig Ingram.
p. 29 Graphic by LISA Symposium XIII. lisasymposium13.lisamission.org
p. 30 Book cover “Gravitational Waves: A history of discovery” by Hartmut Grote, CRC Press, 2019, ISBN 9780367136819
pp. 32-33 Photo of César Rojas-Bravo by Abdo Campillay (p. 32); Swope image from 1M2H Team/UC Santa Cruz & Carnegie Observatories/ Ryan Foley https://reports.news.ucsc.edu/neutron-star-merger/media/
p. 35 Cartoons by Jessica Steinlechner.

Back cover: Illustrations by Nutsinee Kijbunchoo.

Antimatter


THESIS WISHING FOUNTAIN
TIME
ENERGY
SANITY
NUTSINEE KITJUNCHOO ©2020
PLEASE GIMME A THESIS
GRAD SCHOOL
NOPE
ANTIMATTERWEBCOMICS.COM

Welcome to the 18th issue of the LIGO Magazine!

Welcome to the eighteenth issue of the LIGO Magazine! In this issue, Eve Chase and Caitlin Rose give an overview of observations from the first half of Observing Run 3 and their experience of working in lockdown on “The second gravitational-wave transient catalog”. Looking to the future, preparations are underway for Observing Run 4 and we find out what’s been happening at LIGO Hanford, LIGO Livingston, and Virgo in “O4 Commissioning and Upgrades”.

LIGO and Virgo observations of black hole and neutron star mergers have captured imaginations around the world. In this issue we have a special feature on artistic works and collaborations inspired by gravitational-wave science with contributions from artists, musicians, dancers, and scientists on a huge range of projects.

If you are on the lookout for some more reading, check out LIGO India’s new blog! Debarati Chatterjee tells us all about it in “Gravity Matters: A GW science blog from LIGO India”. And LIGO Magazine editor Paul Fulda reviews Harmut Grote’s book “Gravitational Waves: A History of Discovery”.

In this issue’s LAAC Corner, Kamiel Janssens gives a focus on good supervision and mental health in “Building Towards Healthy Supervision” and our “Work after LIGO” series catches up with Craig Ingram on building Earth observation instruments.

Looking back to 2017 in “A discovery in the dark” we revisit the observation of the GW170817 binary neutron star merger with César Rojas-Bravo’s story of capturing the first light with Swope and on being an astronomer from Costa Rica.

And just what are stochastic gravitational waves? Pat Meyers explains on the backpage in this issue’s “How it works”.

As always, please send comments and suggestions for future issues to magazine@ligo.org.

Hannah Middleton, for the Editors

News from the spokesperson

On 5 March 2020, we cancelled the in-person LIGO-Virgo-KAGRA meeting due to concerns about COVID-19. A few days later, the World Health Organization assessed COVID-19 to be a pandemic. After spending a year in more TeamSpeak/Zoom calls than ever, the worldwide roll out of vaccines gives us hope that the worst is over.

Despite the unprecedented challenges, we have continued to succeed as a collaboration. We have released 13 papers in the past 12 months reporting exciting observations of compact binary mergers and important constraints on possible gravitational-wave sources such as cosmic strings and pulsars. And we have many more observational science papers in preparation. These papers are the culmination of many years of work devoted to everything from designing, building and operating the detectors through the qualification, analysis and interpretation of the data. Congratulations and thanks to everybody who works so hard to make our scientific discoveries possible!

We have been making some changes to the organizational structure of the LIGO Scientific Collaboration (LSC) to facilitate even more effective collaboration. Each year, the Program Committee updates the LSC Program (https://dcc.ligo.org/LIGO-M2000130/public) setting short-term goals and long-term strategic vision for the Collaboration. The LSC Program is approved by the LSC Council which is the governing body of our Collaboration; its membership includes representatives from every LSC Group. The program of work is carried out by five Divisions of Observational Science, Instrument Science, Operations, Communications and Education, and Collaboration Standards and Services. Each Division has working groups and committees that specialize in different aspects of the work that we do as a Collaboration. The Management Team includes division, working group, and committee chairs; it coordinates the day-to-day activities of the Collaboration. Being a large, international organization, it can sometimes be difficult to understand how things fit together. Please ask if you have any questions.

Gravitational-wave astronomy continues to generate excitement beyond our immediate scientific community. I want to praise the impressive job of the Communications and Education Division in getting our story out to the public, providing educational materials, and supporting activities like the LIGO-Virgo-KAGRA webinar series. It's also exciting to note that a new LIGO Exploration Center (LExC) is under construction at LIGO Hanford. Together with the Science Education Center at LIGO Livingston, LExC will allow visitors to the observatory to experience science through interactive exhibits.

Preparations for the next observing run (O4) are well underway. The LIGO Laboratory is managing construction, maintenance, and commissioning activities that will increase the reach of the LIGO detectors. The Operations Division is organizing the efforts around calibration, detector characterization, computing, and low-latency analysis so that we will be ready for the increased rate of detections. There is lots of work to be done, so get involved!

Looking further ahead, the Collaboration has a vibrant instrumental research program targeting A+ and beyond. We want to expand the reach of the detectors within the current facilities and we dream of building new detectors capable of detecting gravitational waves from across the whole Universe. We are currently assembling an LSC study group to explore scenarios for post-A+ upgrades to the LIGO detectors with a view to articulating a strategic plan that stretches to the mid 2030s. As part of this exercise, we will carefully consider how each scenario meshes with plans for other detectors including next generation facilities such as Cosmic Explorer and Einstein Telescope.

Patrick Brady
LSC Spokesperson

O4
Commissioning Upgrades

Infrastructure modifications for the construction of 300m long filter cavity needed for the frequency dependent squeezing.

Following an immensely successful third observing run (O3) of the Advanced LIGO and Advanced Virgo detectors, the interferometers are currently undergoing a major upgrade stage to significantly enhance their sensitivity before the next observing run. Francesca Badaracco, Georgia Mendall, Carl Blair and Arnaud Pele give us an update on the status of the upgrades at Virgo, LIGO Hanford and LIGO Livingston.

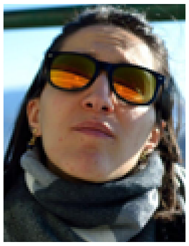
Virgo upgrades

The Advanced Virgo (AdVirgo) detector is currently being upgraded to AdVirgo+ before the next observing run, which is planned to commence in the second half of 2022. The upgrade will be split into two phases, where the first phase aims at reaching a sensitivity of 115 Mpc for the fourth observing run (O4). For reference, the best sensitivity achieved by AdVirgo during O3 was 60 Mpc. Phase I is currently underway and will end at the start of O4. On the other hand, phase II upgrades will commence directly after O4 and last until the start of O5 (around 2025).

So, what upgrades are planned during phase I?

This upgrade will mainly focus on reducing quantum noise, which is a fundamental noise associated with (Heisenberg's) uncertainty in the arrival times of light quanta (photons). It manifests itself in the detector in two ways: shot noise at high frequencies and radiation pressure at low frequencies. In the former case, the uncertainty in the photon arrival time seeps in through a typical shot noise in the photo

Francesca Badaracco



has just started a postdoc at UCLouvain after the end of her PhD. During her PhD, she focused on Newtonian noise active cancellation. However, in her new position, Francesa will be working mainly on Einstein Telescope suspensions and controls as well as cryogenic sensing. In her free time, she loves to go for a walk in the woods, mountains and every possible track immersed in nature. She also loves watching Netflix (a lot)!

by Francesca Badaracco, Georgia Mansell, Carl Blair & Arnaud Pele

Fisheye photograph inside the vacuum tower of the Signal Recycling mir-ror with its surrounding actuation cage and baffles in July 2020.

current at the photodiode. In the latter case, the noise arises from random fluctuations in the pressure exerted by high power laser beams on the mirrors, which cause them to move ever so slightly.

One way to reduce shot noise is by increasing the laser power injected into the interferometer. This will indeed be the case for phase I upgrade where a new laser will be installed to increase laser power from 25W to 40W. Frequency dependent squeezing is another elegant - however technically complicated - solution which allows us to simultaneously reduce both shot noise and radiation pressure noise. This is achieved by injecting light which suppresses radiation pressure noise at low frequencies and then, around 25 Hz, switching to the injection of light which can suppress shot noise. The AdVirgo detector will use a 300m long filter cavity to produce such vacuum states and implement frequency dependent squeezing for the first time!

Another important improvement will be made with the introduction of a signal recycling cavity (SRC). It will be constructed by inserting a mirror at the output end of the detector to reflect some of the gravitational wave signal back into the interferometer, thus amplifying it. The length of the SRC can also be tuned to further reduce the quantum noise. AdVirgo+ will use the so-called wideband configuration in which the SRC is tuned to reduce both the shot noise at high frequencies and radiation pressure noise at low frequencies. However, this comes at the cost of increasing quantum noise in the intermediate frequency band.

Apart from the quantum noise improvements, additional baffles are being installed to reduce scattered light in the interferometer as well as new auxiliary lasers, which have already been installed to help lock the SRC. Moreover, a seismic Newtonian Noise (NN) cancellation system is being implemented to deal with the fluctuations in the gravitational field around the mirrors due to passing seismic waves, which cause them to shake. This will be achieved by using the 76 seismic sensors deployed near the mirrors because of the varying mass distribution, which help in monitoring the seismic noise, estimating NN and actively subtracting it from the interferometer data.

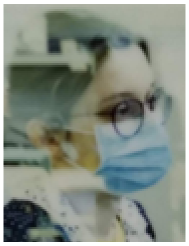
With all of these upgrades, the AdVirgo+ team is looking forward to more space-time bending discoveries in O4.

Getting ready for a new run

Travis Sadecki and Jeff Kissel setting up to measure violin modes on the newly-installed input test mass in the Y arm.

LIGO Hanford upgrade

Georgia Mansell



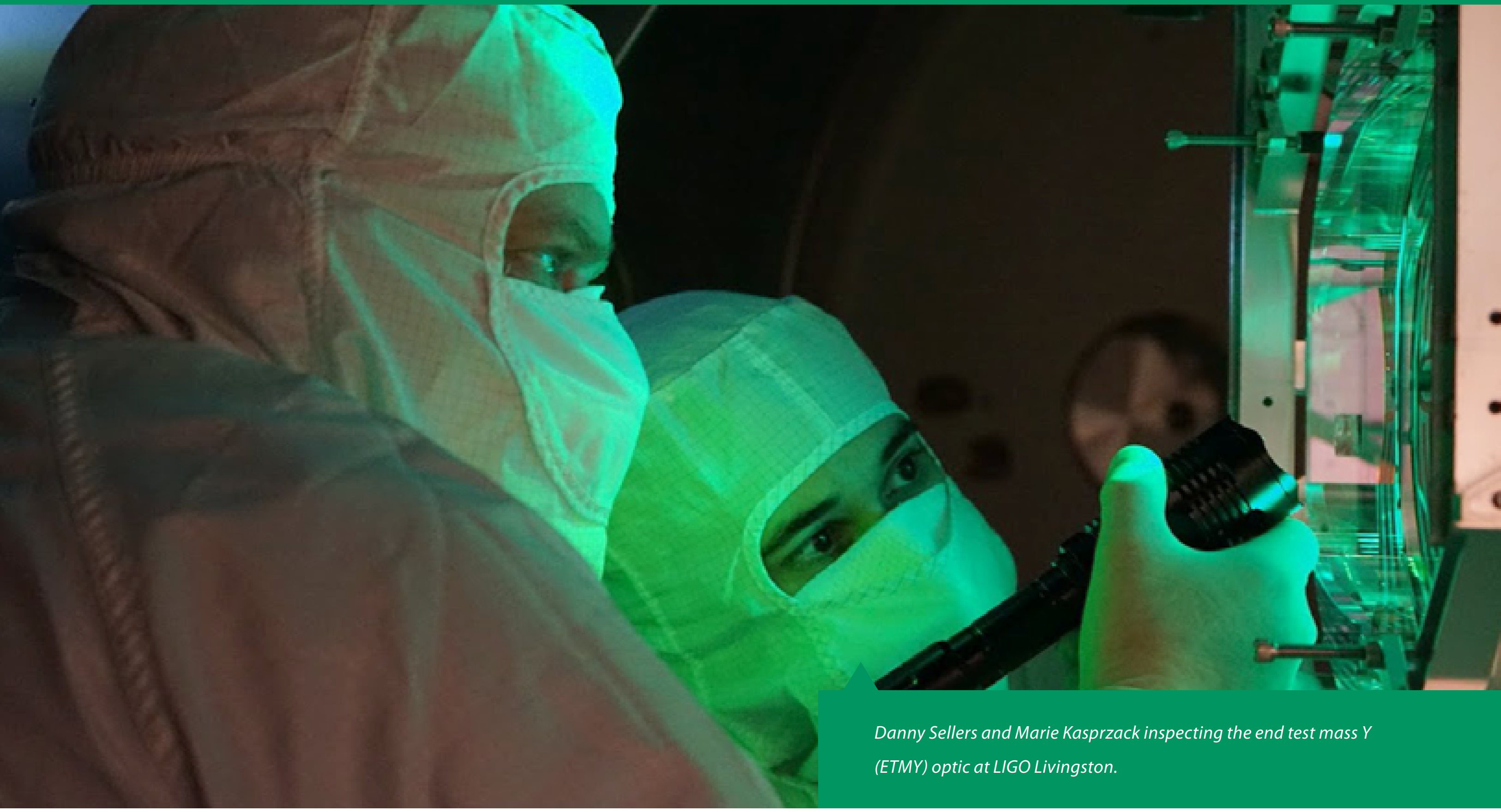
is a postdoc working on interferometer commissioning at LIGO Hanford and MIT. In her spare time, she likes to do yoga, watercolour painting, and making friends with the many neighbourhood cats in Richland.

Several major upgrades are in progress at LIGO Hanford in preparation for O4. A 300m long filter cavity is being added to the corner vacuum envelope to allow us to inject frequency-dependent squeezing. The most problematic test mass of O3 (Input test mass Y) was replaced in December 2020, with the hope that the new mirror is free of point absorbers[1] and will allow higher power operation. For the first time, a test mass will feature violin mode dampers which will reduce the quality factor of the violin modes of the fused silica suspension fibers. A host of new baffles will be installed to help prevent stray light from coupling to the interferometer beam. Additionally, a new high power amplifier is going into the pre-stabilized laser and the existing output Faraday isolator will be replaced with a lower loss one. New in-vacuum controls are being installed on the Hartmann wavefront sensor path, along with a planned upgrade to the gravitational-wave readout electronics. In addition, there are several software and hardware upgrades to the computing systems.

The filter cavity is what I'm going to focus on since it's the most exciting new addition to the interferometer (I am a completely unbiased author). During O3, squeezed light was injected into the output port of the LIGO interferometers. This light was squeezed in the phase quadrature over the full detection band, which means that while we were reducing the interferometer shot noise, we were making noise in the amplitude quadrature - radiation pressure noise - worse. By reflecting the squeezed light off a low-loss filter cavity before injecting it into the interferometer, we can rotate the squeezing ellipse such that we simultaneously reduce shot noise at high frequencies, and radiation pressure noise at low frequencies, giving broadband quantum noise improvement.

This sounds very good in theory, but the implementation is complex: first we need to squeeze another long cavity into the corner station. The filter cavity is too long to fit in the existing

[1] Point absorbers refer to nonuniform localised absorption of laser power in the mirror surface which distorts the surface and introduces loss in the system.



Danny Sellers and Marie Kasprzack inspecting the end test mass Y (ETMY) optic at LIGO Livingston.

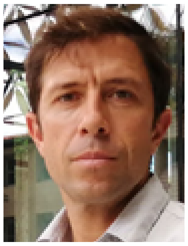
vacuum envelope, so a new section of beam tube will be installed. One of the mirrors of the filter cavity will sit in the new Horizontal Access Module 7 (HAM7) chamber, next to the existing HAM5 chamber where the signal recycling mirror lives. In fact, our new HAM chamber is already in place. The other end mirror will be in HAM8, which will sit in a new building dubbed the "HAM shack", next to the y-arm. Locking the filter cavity is a fiddly endeavor, as the cavity must have a very high finesse (~5000). The locking scheme involves two beams, one at 532nm and another at 1064nm which is frequency-offset from the main interferometer beam. The in-air sections of these paths have been installed. Commissioning of the filter cavity is scheduled to begin around the fall of 2021. We'll keep you posted on the latest updates through the LIGO alog!

LIGO Livingston upgrade

The LIGO Livingston upgrades are going full steam ahead under the spectre of COVID and social distancing. Following the end of O3 in March 2020, a short vent in September 2020 was carefully planned with enhanced safety measures to inspect, map out and clean absorptive features on the end test mass Y (ETMY) optic. Additionally, mechanical dampers were added to the cryo-baffles and additional baffles were installed around the transmission optics to reduce scattering noise coupling into the interferometer. Since then, the detector has been locked, achieving a sensitivity of 130Mpc, which is similar to O3 sensitivity.

During O3, phase squeezed light was used to reduce shot noise above ~100Hz. However, this degraded the sensitivity at low frequencies due to the increased back-action noise or radiation pressure noise. This issue can be resolved using a filter cavity to rotate the squeezed vacuum ellipse and simul-

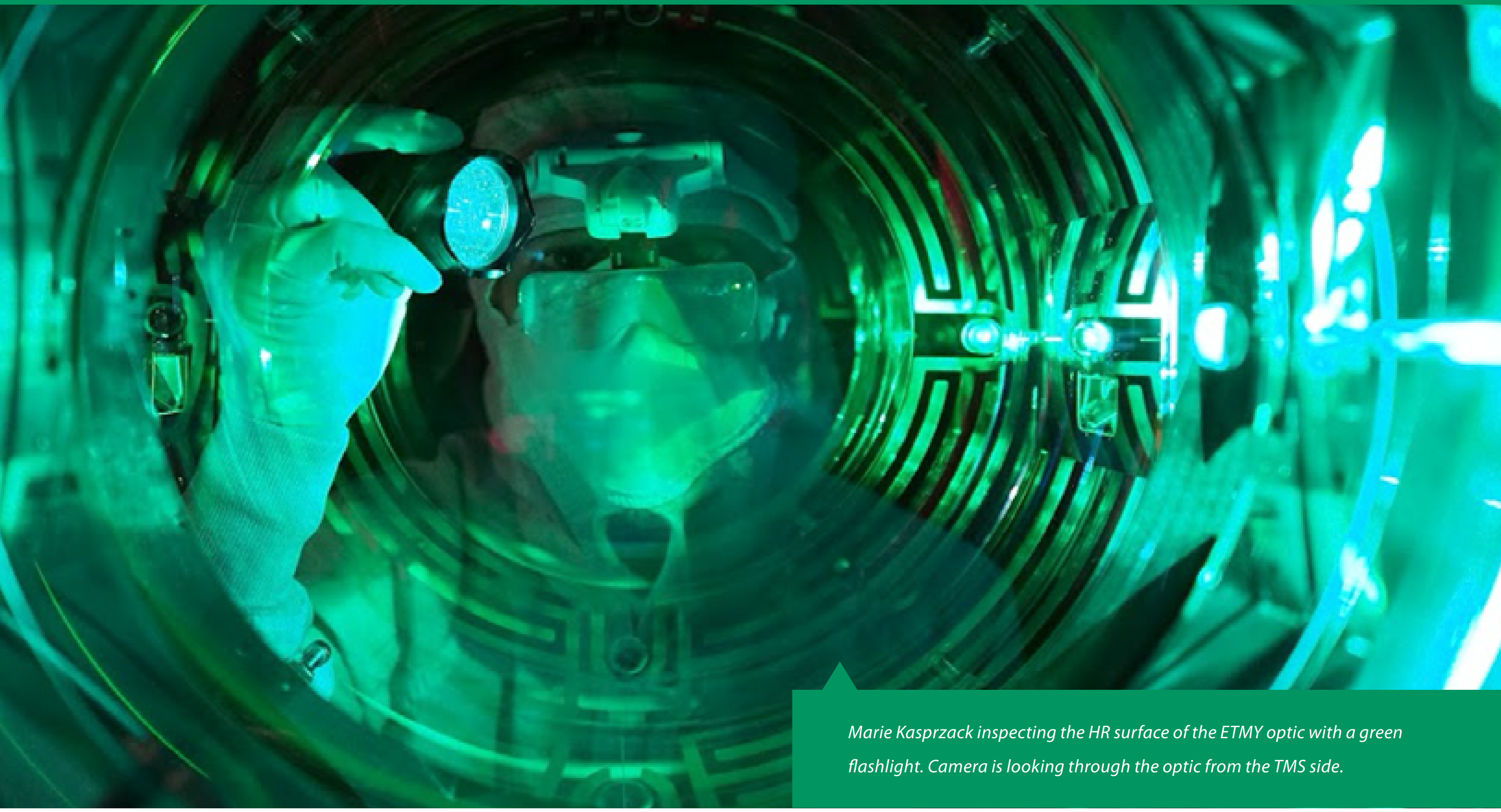
Carl Blair



is an experimental physicist developing techniques to make better gravitational wave detectors at University of Western Australia. Carl enjoys anything that slides on water (frozen or otherwise) or rolls on 2 wheels and loves playing with gravitational wave detectors.

Arnaud Pele

is a mechanical engineer at the LIGO Livingston observatory, part of the detector engineering group. He enjoys running in the hot and humid Louisiana weather and recently started woodworking projects.

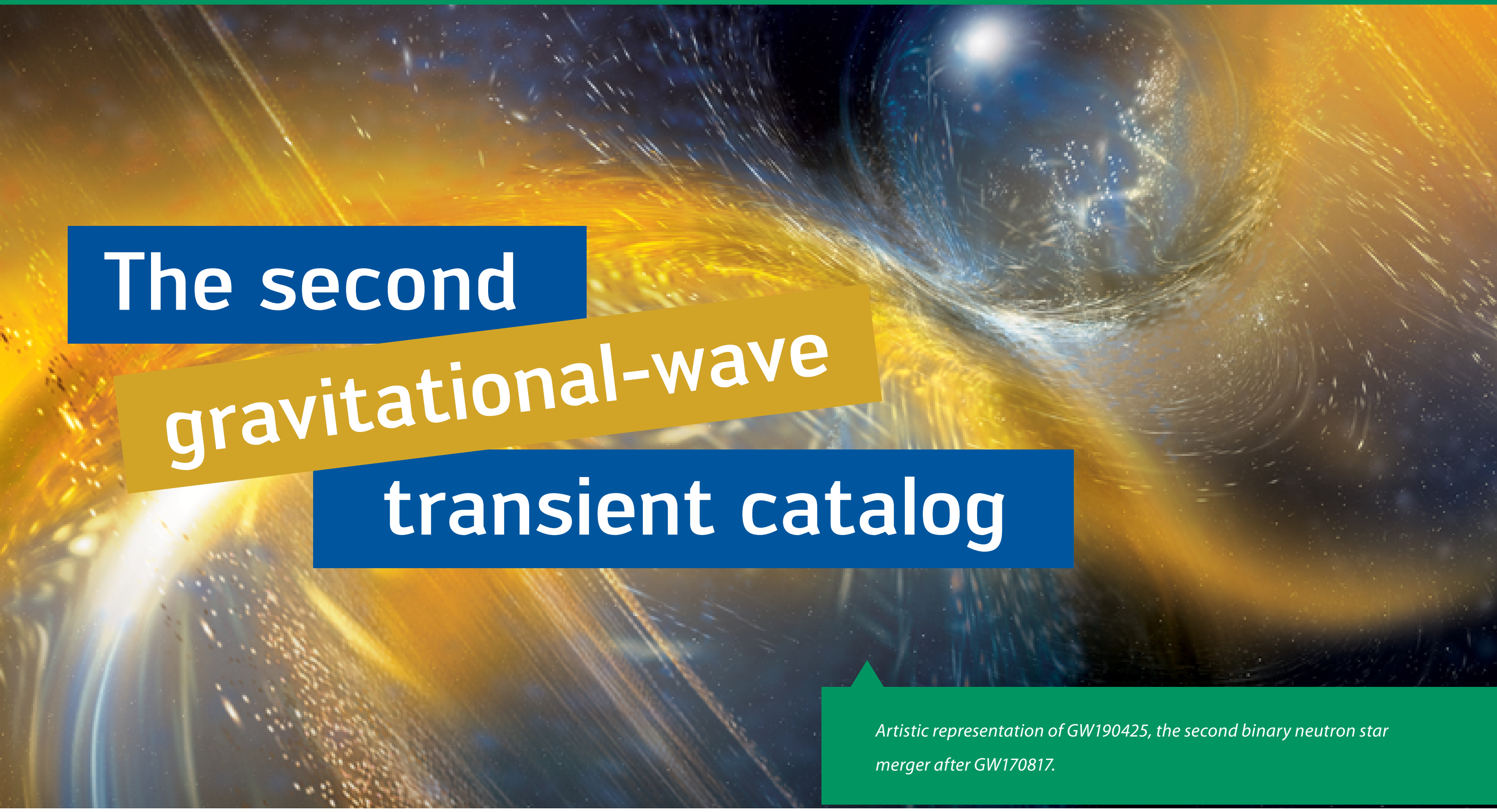


Marie Kasprzack inspecting the HR surface of the ETMY optic with a green flashlight. Camera is looking through the optic from the TMS side.

taneously reduce both of these noise sources across the entire gravitational wave detection band.

Major commissioning work is currently underway to construct such a cavity before O4. Among these include the big installation of the vacuum enclosure for the new filter cavity, construction of new buildings, new HAM chambers with new optical tables, suspensions and novel optics and a new beam-path through an input test mass vacuum chamber. The first of two HAM vacuum chambers have been constructed and placed in the Laser and Vacuum Equipment Area (i.e., the main lab). The second chamber will sit in a purpose built building 300m down the interferometer arm. The corresponding tables and suspension systems are being built and tested on site before installation. Various critical technologies such as adaptive optics are being assembled and tested around the world and will be delivered to the Livingston site in due course.

Due to the COVID-19 pandemic, commissioners are no longer allowed to work from the control rooms. Instead, they access control computers from their personal offices or homes and stay connected via teamspeak or zoom. Even with these restrictions in place, various other commissioning tasks are being performed in parallel with the construction of the filter cavity. This includes an investigation into potential scattering noise sources which revealed a cryobaffle as a problem. It also revealed coupling of acoustic noise at the X-end of the detector which depends on beam spot position. Additionally, the beam position motion is known to produce non-linear interferometer noise. Camera beam position monitors are currently being investigated to improve beam position monitoring. The critical differential arm length (DARM) control drive has been split between ETMX and ETMY. This allows larger control signals in noisy environmental conditions, thus making the detector more robust. A more powerful beam splitter drive has been commissioned to make the locking procedure more robust. This is only a small subset of commissioning work that has been done and is planned for the O4 upgrade. Check out the alog or commissioning meeting recordings for more.



The second gravitational-wave transient catalog

Artistic representation of GW190425, the second binary neutron star merger after GW170817.

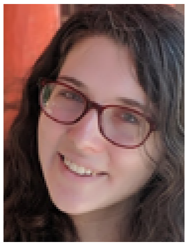
Well, 2020 turned out to be quite a year: a pandemic was declared, conferences canceled, the observing run suspended, and before we knew it, we were working from home. Dining tables transformed into offices and sweatpants became common workplace attire. The days became monotonous as life-saving lockdowns were extended for weeks, then for months, and now for over a year, all while we waited for a vaccine. But as the pandemic progressed, we were grateful that the nature of our work within an international scientific collaboration provided us with the technology to continue our research remotely.

As the world hunkered down to stop the spread of a deadly virus, the LVC (LIGO and Virgo Collaboration) got busy analyzing the gravitational-wave data of the O3 science run from makeshift home offices around the globe.

O3a and O3b are the first and second halves of LIGO and Virgo's third observing run. O3a lasted from April 1st to October 1st 2019, while O3b began on November 1st and ended prematurely on March 27th 2020 due to the pandemic. Last October, the collaboration introduced 39 events from O3a to our second gravitational-wave transient catalog (GWTC-2) and will publish the detections of O3b later this year.

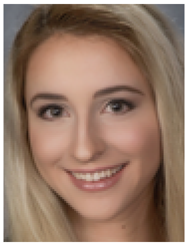
Remarkably, O3a alone recorded over three times more gravitational-wave events compared to LIGO and Virgo's two previous observing runs combined.

Eve Chase

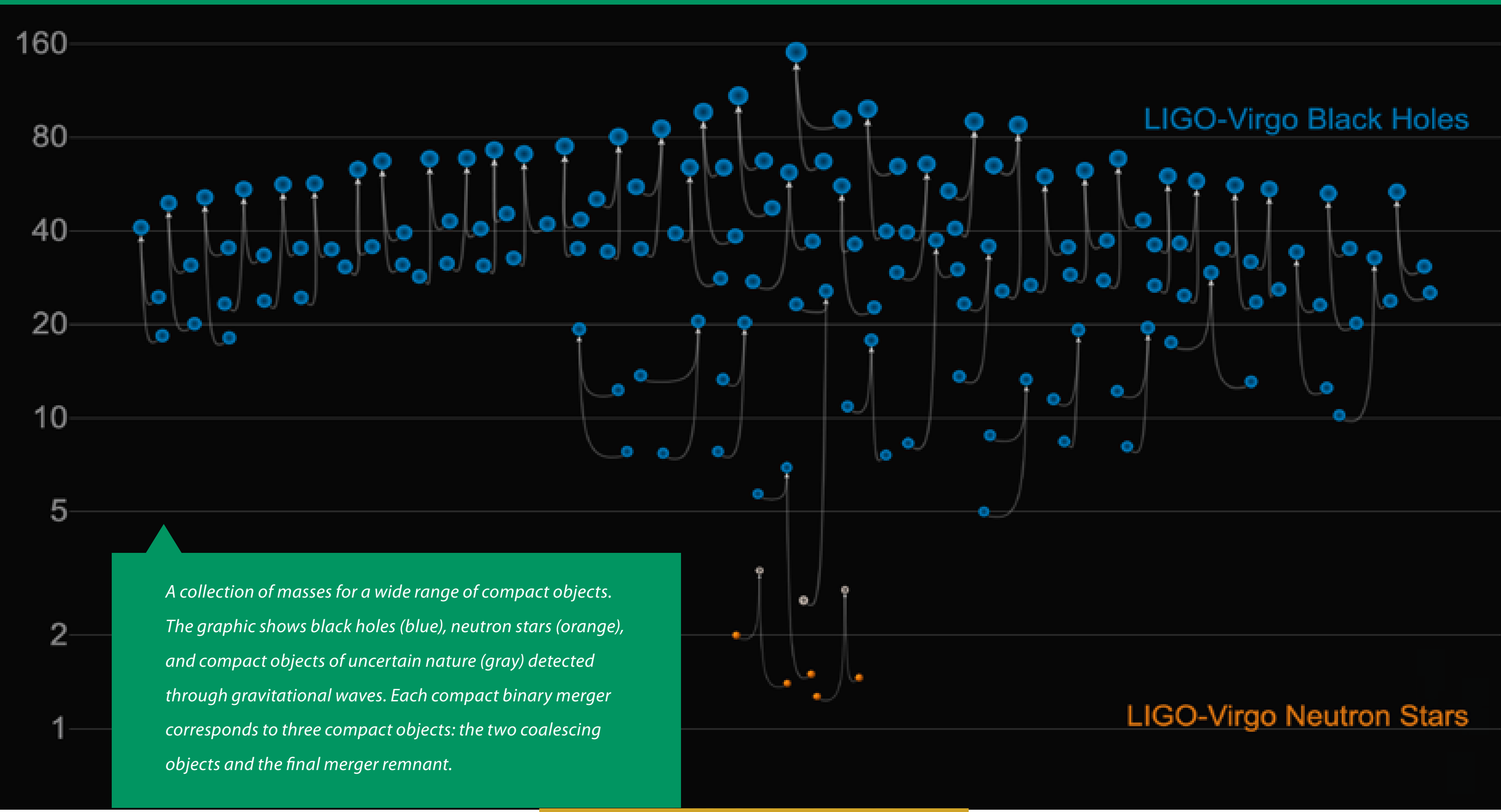


is a PhD student at Northwestern University who uses data science to study neutron star mergers. She hopes to improve her karaoke skills in time for the next in-person LVK collaboration meeting.

Caitlin Rose



is a PhD student at the University of Wisconsin-Milwaukee who works on rapid parameter estimation of gravitational-wave sources. She also enjoys board games and Friday happy hour with colleagues.



A collection of masses for a wide range of compact objects. The graphic shows black holes (blue), neutron stars (orange), and compact objects of uncertain nature (gray) detected through gravitational waves. Each compact binary merger corresponds to three compact objects: the two coalescing objects and the final merger remnant.

This was the result of the Virgo detector running for the entirety of O3a, as well as major improvements within the interferometers and data analysis methods, extending our view of the gravitational-wave universe further than ever before.

Among the many discoveries of O3a is GW190425, the second ever binary neutron star (BNS) merger, after GW170817. But even more extraordinarily, for the first time we encountered two events consistent with the coalescence of a neutron star and a black hole (NSBH). GW190426_152155 is the first NSBH candidate, with inferred component masses of 5.7 and 1.5 times the mass of the Sun (solar masses). GW190814 is a highly asymmetric system of ambiguous nature, corresponding to the merger of a 23 solar mass black hole with a 2.6 solar mass compact object, which is either the lightest black hole or heaviest neutron star observed in a compact binary.

What's in a name?

The first six numbers of a GW event name are the year, month, and day of the observation. The longer names show the time of the event after the underscore in UTC (Coordinated Universal Time). For example, GW190924_021846 was detected on September 24, 2019 at 02:18:46 UTC

Another particularly asymmetric candidate is GW190412, the first binary black hole (BBH) observation with unequivocally unequal component masses. Nearly twice the mass of the heaviest BBH of GWTC-1, GW190521 is the most massive BBH of GWTC-2, with a total mass of 150 times the mass of the Sun. GW190924_021846 contains the lowest mass black hole ever detected with gravitational waves (excluding GW190814's ambiguous compact object), with a mass around 5 solar masses. By analyzing all of GWTC-2's black holes in conjunction, we measure the distribution of black hole masses in the local universe, which in turn reveals histories of binary black hole formation and stellar astronomy.

Masses are not the only information we gain about the compact objects; we can also measure how much they are spinning using gravitational-wave observations. The magnitude and direction of each compact object's spin, in addition to mass, encode evidence of binary precession. Precession refers to the wobbling of the binary's orbital plane about a fixed angle, similarly to a rapidly spinning top. GWTC-2 contains individual events which may support mild evidence for precession, such as GW190412 and GW190521. However, hints of precession in binary orbits are evident when analyzing all binary black hole events in GWTC-2 in unison.

O3a highlights

GW190425: This observation is consistent with being a binary neutron star, the second binary neutron star observed (after GW170817).

GW190412: The two black holes in this binary have asymmetric masses – one black hole is more massive than the other. This is the first observation where we are confident of asymmetric masses.

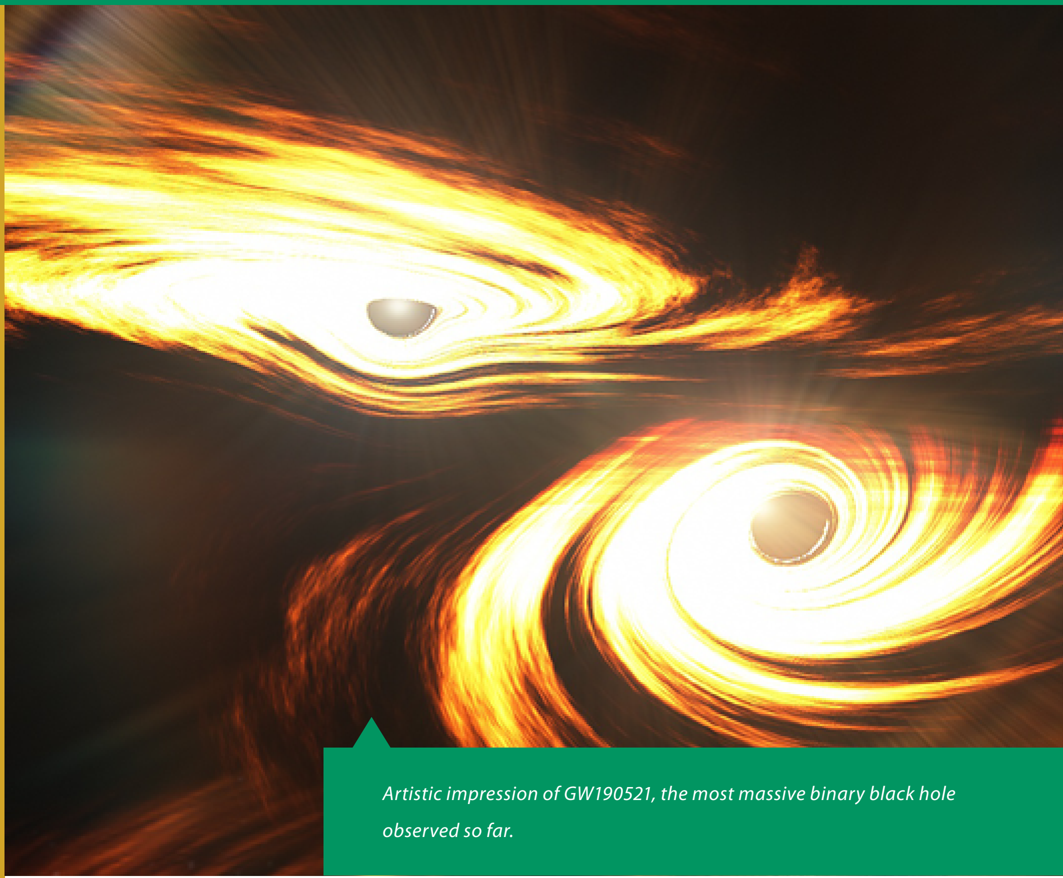
GW190426_152155: The origin of this observation is uncertain. If it is astrophysical, it could be a neutron star merging with a black hole.

GW190521: The most massive binary black hole observed so far. The two black holes have a combined mass of about 150 times the mass of our Sun.

GW190814: A merger between a black hole with an object which could either be a black hole or a neutron star. If it is a neutron star, it is the most massive neutron star observed. If it is a black hole, it is the least massive black hole observed.

GW190909_114149: A massive binary black hole and likely the most distant gravitational-wave event ever detected.

GW190924_021846: Likely the lowest-mass binary black hole system detected to-date, excluding GW190814.



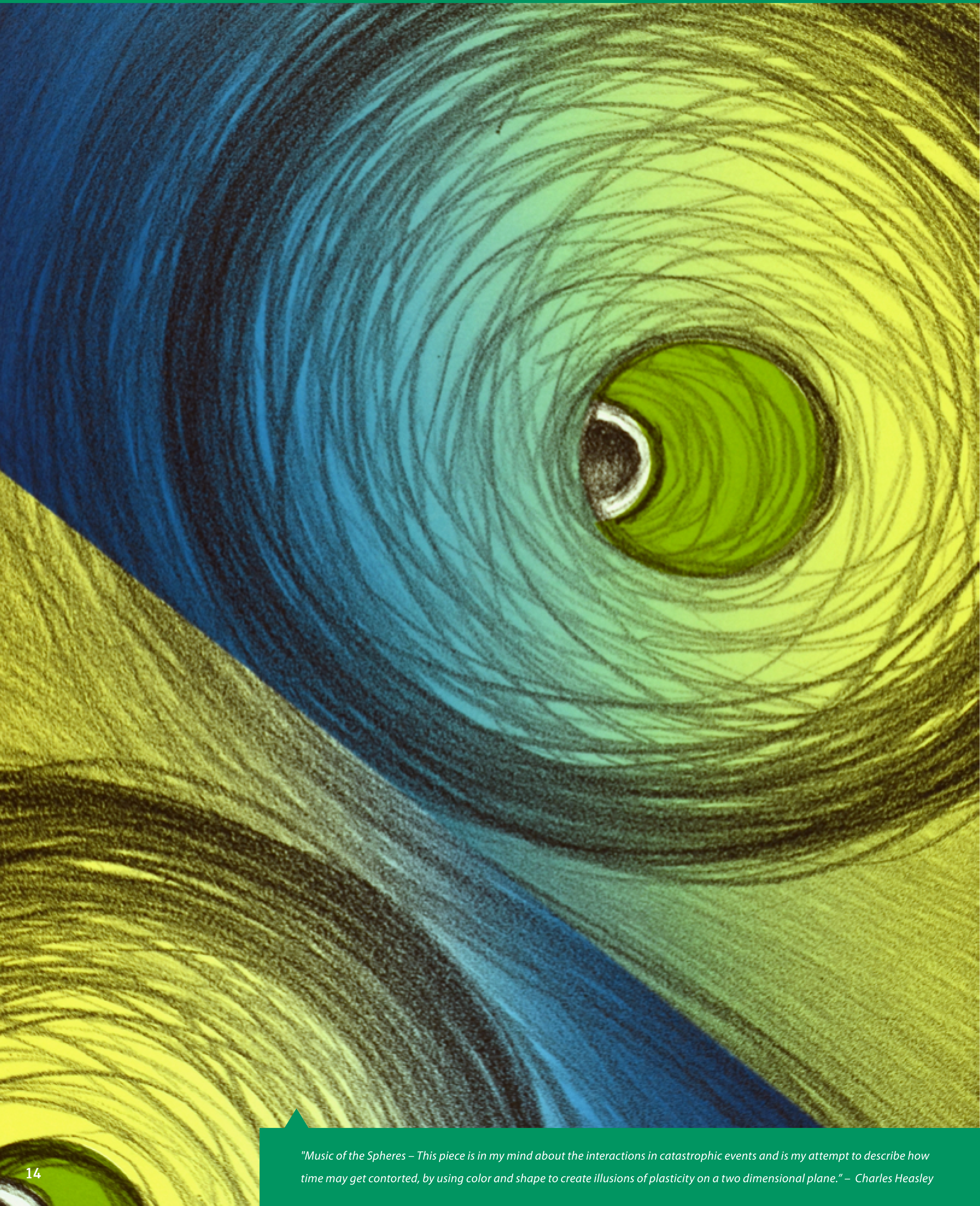
Artistic impression of GW190521, the most massive binary black hole observed so far.

Every new discovery in O3a increases our understanding of the universe. Binary masses and spins tell us a wealth of information on the history and formation of black holes and neutron stars. These measurements promote the strongest tests of general relativity through gravitational waves, while also enhancing our independent measurement of the universe's expansion rate. GWTC-2 spans a diverse and unique range of astrophysical parameters, ushering in many firsts for the burgeoning field of gravitational-wave astronomy.

The future of gravitational-wave astronomy is increasingly promising. In the coming months, our catalog of gravitational-wave events will expand to include events from O3b for which over 20 triggers have already been publicly released. In the meantime, scientists will continue to improve the detectors, further increasing our astrophysical reach in time for the fourth observing run, set to begin in 2022.

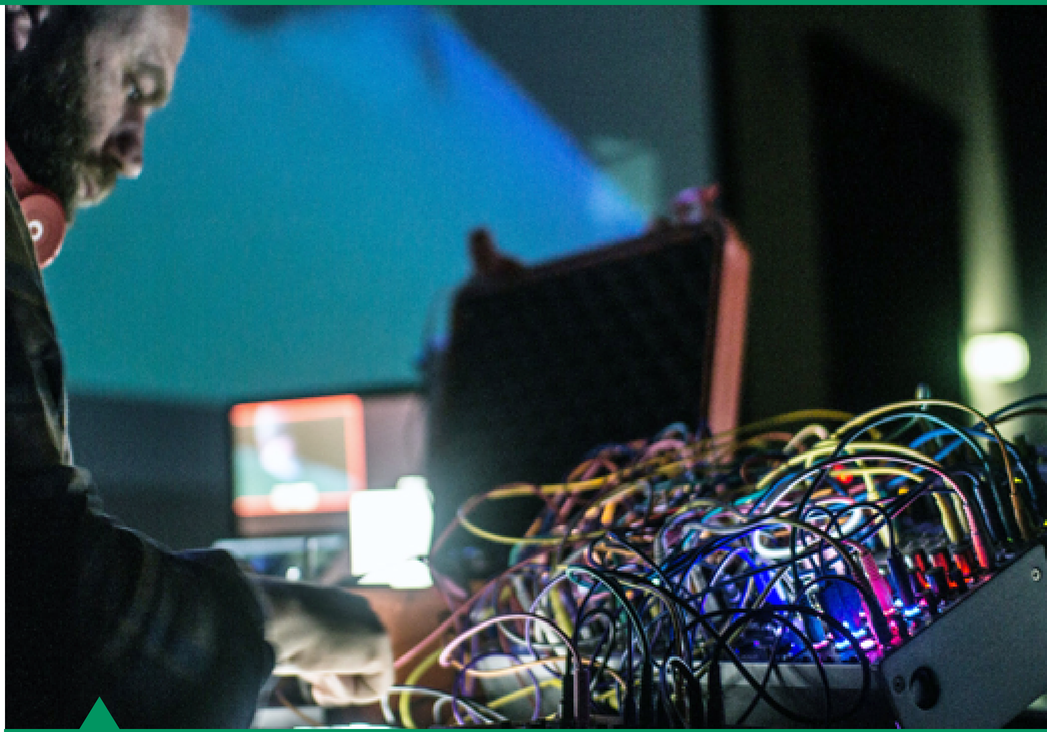
When we started our PhD programs in the Fall of 2016, there were only three gravitational-wave detections in existence. Now, in our fifth year of graduate school, the LVC has published 50 confident gravitational-wave detections. We experienced the excitement of analyzing O3a events and watching this field blossom and grow with us as we find our way as young scientists. It's overwhelming sometimes to think about the chaos happening in the world right now due to the pandemic. But the subject of our work, thinking about black holes colliding in space, is truly the best distraction.

Art and music …



"Music of the Spheres – This piece is in my mind about the interactions in catastrophic events and is my attempt to describe how time may get contorted, by using color and shape to create illusions of plasticity on a two dimensional plane." – Charles Heasley

Where imagination meets science



Leon Trimble with Gravity Synth at the Live Performers Meeting, Rome.

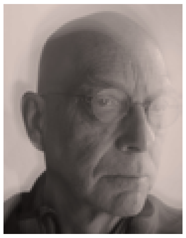
Gravitational wave observations have captured imaginations around the world. In this article we hear from artists, musicians, and scientists on their gravitational wave inspired artistic works.

Einstein's Unfinished Symphony

My work is usually created by combining expressive or gestural hand drawn elements with photographic or light sensitive printing matrices. My specialized interest has been primarily in the area of photo print processes of the late eighteenth through the early part of the twentieth century. I have always had an interest in the way the sciences dovetail with the arts and since about 2001 I have been watching with great anticipation the way LIGO and the other gravitational wave observatories have proved successful in their objectives. I first became aware of the investigations when I read an article that was published in the New York Times book review of Marcia Bartusiak's book "Einstein's Unfinished Symphony". This work became a springboard for my imagery and subsequent prints over the past twenty years.

I am now in the final stages of completing a suite of eight lithographs drawn on stone with color superstructure formed on photo sensitive lithographic plates, which I am dedicating to Marcia Bartusiak and her profound ability to take such a complex subject and translate through verbal language the ideas of science. Her works reveal the real creative individuals are and their vast achievements through the science of the LIGO experiment.

Charles Heasley



is a member of the Department of Art and Art History at the State University of New York College at Cortland. He teaches in the Graphic Design and Digital Media program and conducts courses in analog and digital Photography, Motion and Graphic Design, and Printmaking.

Gravity Synth

Gravitational waves signals can be converted into sound, but did you know that the technology used to detect them can be used to make music? Gravity Synth does just that: it is a musical instrument created by combining a Michelson interferometer with a modular synthesiser.

It is a collaboration between audiovisual artist Leon Trimble and University of Birmingham researchers, Aaron W. Jones, Conner Gettings, Hannah Middleton, Anna Green and Andreas Freise. In 2016, Leon and Hannah met at an art/science "Worlds Collide" event in Birmingham and got chatting about black holes making chirp signals when they collide and converting gravitational-wave signals into sound. This led to many more discussions between Leon and the research group members. Meanwhile, Aaron designed and built the interferometer for use in live performances.

During performances, tones from the interferometer are pulsed by vibrations and combined with synthesiser voices, drum machines, and laser projections to create an audiovisual experience. Gravity Synth has performed at BBC Digital Planet, Gravity Fields (in Isaac Newton's family home, Woolsthorpe Manor), and TEDx. Its sounds have even been to the moon and back at Music Tech Fest (2018) where the sound was transmitted from a disused nuclear reactor at the KTH Royal Academy, to be moonbounced (Earth-Moon-Earth communication) via the Dwingeloo Radio Observatory in the Netherlands, before being played back to the audience.

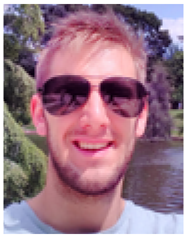
The project is a parallel journey for both artist and scientist through interdisciplinary learning. It explores how science takes a subject, turns it into data and relates it to a wider public; while art does a similar thing for an audience, with a concept and a medium.

Listen to Gravity Synth: chromatouch.bandcamp.com/album/gravity-synth-ep and find out more: gravitysynth.tumblr.com.

Leon Trimble

is a digital artist who works in audiovisual performance. He specialises in immersive video and synth design and runs a 360 degree immersive video dome at English summer festivals with an exciting programme of music and video.

Aaron Jones

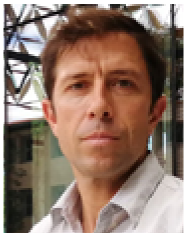


recently completed his PhD at the University of Birmingham and is now a Post Doc at the University of Western Australia working on laser mode-matching schemes and 2um technology for Gravitational Wave detectors.

The sounds of GW150914

In the excitement following the first detection of gravitational waves I had a couple of attempts to reproduce the sound of GW150914 on my cello. One of these attempts got into the TV news, which led to a collaboration with Nick Bannon from the University of Western Australia (UWA) music department and a cello duet with Arianne Jacobs to celebrate science and the detection of gravitational waves. Nick is a very interesting character, walking in the footsteps of Galileo he researches interactions between music and science.

Carl Blair



is an experimental physicist developing techniques to make better gravitational wave detectors at University of Western Australia. Carl enjoys anything that slides on water (frozen or otherwise) or rolls on two wheels and loves playing with gravitational wave detectors.

Nick left UWA last year and in his farewell lecture he took the audience on a fascinating journey through time; relating Music, Language, Science and Human Evolution. The lecture was equally well received by musicians, phycologists and physicists. Arianne is a brilliant musician who recently graduated from the UWA Conservatory of Music with First Class Honours in music performance. She has been awarded a swath of awards, including the prestigious VOSE memorial prize and the UWA Lady Callaway Medal for Music for outstanding performance in her undergraduate degree. She is a much loved music teacher.

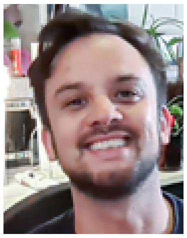
The performance can be found here https://www.youtube.com/watch?v=8RXLSDefoAY and with descriptions here https://www.youtube.com/watch?v=5t-XuR4IPjo.

Capturing the imagination

Visualising gravitational waves has been the most challenging and rewarding job I've ever had. I used to use my skills to e.g. market soft drinks. Science is much more captivating.

Whenever I'm creating science-based art it always starts with a long, usually excited talk with the researchers. I ask a lot of questions. I want to know what are the key elements that must come across to the audience. My job is to translate the words of the researcher into a striking visual that will grab the viewer instantly and get them to read more.

Carl Knox



has been a professional artist for 20 years, working in games studies, advertising agencies and as a University lecturer before finding a full-time position at OzGrav ARC Centre of Excellence for Gravitational Wave Discovery since 2017. Carl loves walking the dog and playing piano whenever needing a break from the computer. Follow me on Instagram @knoxcarl

Gravitational wave detector (laser interferometer) by Carl Knox.

The music of gravitational waves

I've known Samaya since we went to school, and then university together. Samaya's work has always been something of a wonder to me so when we had this chance to do something around gravitational waves I jumped at it.

Samaya gave me both the models and the detections as wav files (high resolution audio files). I mapped their pitch on to a stave so we had a series of melodies tracking the exponential curves. This gave me the musical motifs against which I then put percussive lines made up of the chopped, stretched and morphed original audio files.

Against that I wrote a more tonal string backing which we included in a recording session with The City of Prague Philharmonic which we were doing for a separate album. This was back in 2016 and we've been tied up with albums since then. Now I'm back working on this project and we hope to start releasing things this year.

Arthur's TEDx talk "Emotions from distortions in spacetime" can be viewed here: https://www.youtube.com/watch?v=MHc3iBH-Tmo. Find out more at: http://www.epcmusic.com/space.

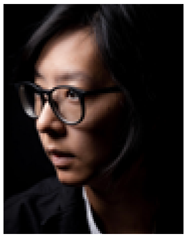
Arthur Jeffes & Samaya Nissanke

Arthur Jeffes is a composer and musician who mainly works with his band Penguin Cafe. He has been working with Samaya Nissanke who is Associate Professor and spokesperson of GRAPPA (a centre of excellence in gravitation and astroparticle physics) at the University of Amsterdam. In collaboration with Samaya, Arthur has been creating music with gravitational waves.

LIGO's Nobel laureate paintings

First painting – This painting was done in 2016. It was the year LIGO announced the first detection of gravitational waves. Some people (including me) were hoping we would win that year and the prize would have been awarded to Rai Weiss, Kip Thorne, and Ron Drever. Turned out that was a bit too soon. The painting was done on the night of the Physics Nobel Prize announcement (before it was announced). My cat (named Einstein) was sitting for a scale (and probably judging)!

Nutsinee Kijbunchoo



is a final year PhD student working on quantum optics at the Australian National University, and has so far spent about half the time at LIGO Hanford. "I lab, drink, and draw things".

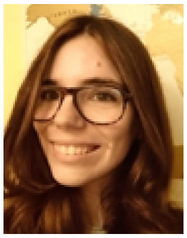
Second painting – So LIGO didn't win the Nobel Prize in 2016 but we did the next year. Ron passed away so the award went to Barry Barish (I wonder if Ron knew how close he was to winning the Nobel Prize). The first painting I did was hung on the hallway wall between the control room and the LVEA entrance at Hanford. It was a bit awkward for Mike Landry when Barry visited the site and Ron's painting was there with the other two laureates. So he asked if I could do another one with Barry instead of Ron. Inspired by Jackson Pollock I found a leftover house paint and tried drip painting technique. The paint was extremely difficult to control! The painting was done in 2018 when I visited the site as a grad student.

Because I moved around a lot I didn't carry many sophisticated painting tools with me. Both paintings were done with a toothbrush and a sponge to fill in the black. If there was a painting studio I could rent I probably would have gone crazier with the paint splashing!

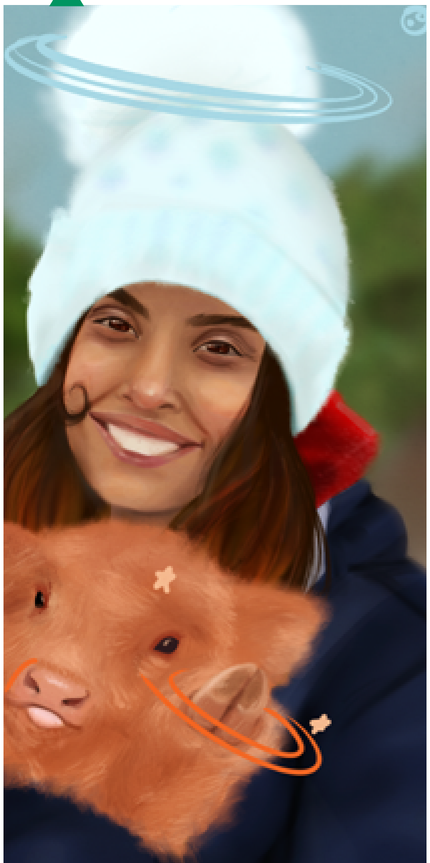
Portraits of LIGO

"Portraits of LIGO" is a series of portraits of eight (for now!) scientists from the LIGO collaboration. In the spirit of the Humans of LIGO blog, the goal of this project is to highlight the humans who make up the collaboration. Each subject chose some elements that would go into the composition of their portrait: dream jobs, important aspects of their work, animals... Portraits of scientists are often made after they've won significant prizes for their research. After seeing portraits of Kip Thorne, Rainer Weiss and Barry Barish, I thought the rest of the collaboration deserved some portraits too, since their contributions are all important!

Laurence Datrier



is a PhD student at the University of Glasgow. Usually a travel enthusiast, during lockdown when she's not painting or working she can be found cycling, running or learning Scottish Gaelic.



Vaishali Adya

Debarati Chatterjee

Kelly Ricks

is an artist and amateur astronomer based in New Mexico. Her drawings and other creative explorations can be viewed on her website: www.deepskykelly.com.

Data-inspired crochet

Early in 2020, I was inspired by an article on the Colossal Blog* to crochet an afghan based on each day's high temperature. I was fascinated by the patterns of color emerging day by day: data, art, and memory all rolled into one. I enjoyed it so much that I decided to crochet more data-inspired projects. Using raw numerical data, I made scarves based on the emission spectrum of Hydrogen, a 2017 supernova light curve, and most recently, LIGO's first detection of gravitational waves: GW150914. To access the data, I contacted LIGO and heard back from Jonah Kanner the very next day. He directed me to an online data viewer** where I was able to adjust raw data from GW150914 and create a pattern. After crocheting the colored background, I overlaid an image of the frequency plot and was delighted to see that it fit perfectly!

References

*https://www.thisiscolossal.com/2020/02/weather-blankets-climate-crisis/

**https://share.streamlit.io/jkanner/streamlit-dataview/master/app.py/+/

Crochet scarf by Kelly Ricks. The pattern is based on data from GW150914, the first detection of gravitational waves from a binary black hole merger.

Downeast Rapid Transit

Ask a Mainer how to get to LIGO, and you used to get the salty reply: “You can’t get there from here.” But how times have changed. Now you might hear: “Just hop on the Spruce Line, change at Cherryfield to Lake. It’s the next stop. You can’t miss it.”

JT Bullitt

is an independent seismologist, sound artist, and planetary listener. He lives in Cambridge, MA and Steuben, ME. For more information on Downeast Rapid Transit visit: DowneastRapidTransit.com

Yes, there really is a subway in rural Maine – or at least the dream of one. Downeast Rapid Transit (DRT) was a public art project in eastern Maine: an imaginary underground subway system to help bridge the far-flung communities of remote Washington County.

Between 2015-2018 some two dozen area residents and merchants volunteered to erect custom DRT subway station signs in front of their homes and businesses. These unexpected hints of a previously unknown subway system scattered across the countryside provoked both laughter and serious conversation about the nature of social isolation and connectedness in rural Maine.

In 2016 DRT inaugurated its 18th station, in the blueberry barrens outside Cherryfield, to commemorate the site of what would have been the control room of LIGO’s eastern detector, had the political winds of the 1980’s blown differently. (The NSF eventually selected an alternate site near Livingston, Louisiana.) DRT invited LIGO physicists Peter Saulson (Syracuse University) and Rai Weiss (MIT) to serve jointly as station masters. They proved to be a good match. The following year their excellence in station mastery was formally acknowledged, and LIGO became the first subway station in history to be run by a Nobel laureate.

Crystal gazing

The white surface inside the crystal ball represents a volume of the universe where the gravitational-wave source is more likely to be. It is constructed accurately from the LIGO localization results using publicly available data. It's fascinating the variety of shapes that shows up for each event. And for once, I like that the worse the localization, the richer the shape in the crystal ball.

I've been practising with open source graphics design and rendering software (Blender and Inkscape, mostly) over the last 14 years. It is really stimulating to me to find a way to visualize, and if possible, materialize a piece

Riccardo Buscicchio

is a final year PhD student at the University of Birmingham, United Kingdom. His work focuses on developing new Bayesian inference methods for LIGO and LISA, filling the gap between individual detections and stochastic background. In his spare time, he enjoys digital sculpting and mixing photography with 3D renderings.

of scientific information. This time I wanted to convey a feeling I have for every new observed event; just like crystal-gazing unveil the future, a new detection unveils a distant past. Check out all other events' 3D maps in the gravitational wave alert app "Chirp".

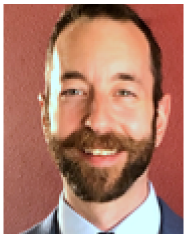
Roundabouts in Richland

Recently, the City of Richland and its all-volunteer Arts Commission worked with Rhiza A+D, an architecture firm out of Portland, OR, to create new public art sculptures installed in two of Richland's roundabouts. The two pieces, built as a pair, are called 'Waves of Viticulture' and 'Fishing for Gravity.'

The surrounding rock landscape is two-toned, rippled and spiraling to represent the corresponding waves, both water and gravitational. 'Waves of viticulture' is similarly rippled – both from the gravity of the adjacent tumultuous spacetime, and to represent the waves seen in a river. It also doubles as a wine vineyard, with the cross-section of each row having the profile of a grape vine leaf and "grapes" formed with the recycled bottoms of wine bottles. The City and Rhiza A+D are as excited as we are that this collaboration resulted in such stunning visual representations that includes LIGO and gravitational waves.

"Virgo mirrors are a fundamental part of our interferometer, although sometimes you also need to work at home with more common mirrors." – Isabel Cordero Carrión

Jeff Kissel



is the Controls Engineer for the LIGO Hanford Observatory. By day, you'll find him neck-deep working on the myriad of control systems needed to achieve LIGO's ground-breaking sensitivity. As current chair of the Richland Arts Commission [1] he worked with Rhiza A+D (http://rhiza.rhizaaplusd.com/) on the design of the Art within the roundabouts highlighted.

The sculptures represent the collection of symbiotic dichotomies that Richland has become: rich natural resources used in the context of modern sustainability practices; a booming agriculture economy coupled with high tech industry; cutting edge science in an area rich with cultural traditions, to name a few examples. 'Fishing for Gravity' alludes to giant net being pulled out of the local rivers full of fish – harkening to the rivers as one of the city's primary natural resources – while at the same time doubling as the gravitational well of two colliding black holes – in direct homage to LIGO and its Nobel Prize winning discoveries.

"Waves of Viticulture" roundabout sculpture in the City of Richland.

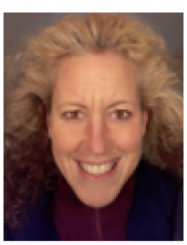
"Fishing for Gravity" roundabout sculpture in the City of Richland.

[1] https://www.ci.richland.wa.us/government/boards-commissions-and-committees/arts-commission

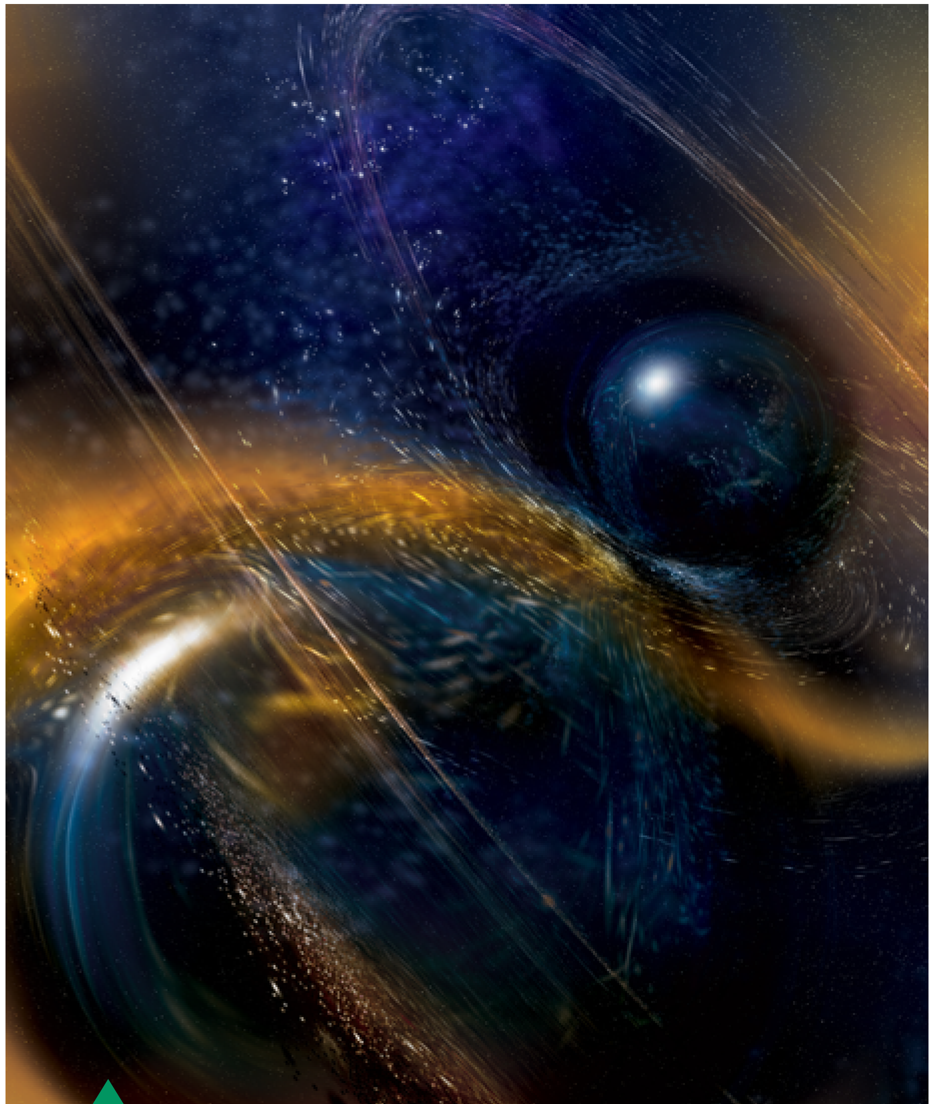
Illustrating the discoveries

In my work I collaborate with LIGO physicists to create digital illustrations of astrophysical phenomena revealed by the facility. My goal is to make these faraway and abstract events accessible to as many people as possible. To accomplish this, I take the detailed inputs given to me by the scientists and combine them with my own intuition and creativity, along with familiar patterns found in nature, to create visuals that will be comprehensible to non-experts. This all began with the team's first detection, announced in 2016. Since then, my artwork has accompanied just about every big LIGO announcement — in press conferences, in popular videos on YouTube, and in The New York Times among others.

Aurore Simonet



is a scientific illustrator at Sonoma State University (SSU) in California. When not creating inspiring space images, she enjoys hanging out upside down in a swimming pool (she is an accomplished artistic swimmer) and finding peace and rejuvenation hiking along the beautiful Sonoma County coastline.



GW190425: Illustration of a binary neutron star merger by Aurore Simonnet

Unfolding Collaborative Art

As an artist, I communicate the splendor of our universe by creating handwoven, sculptural artworks. I translate scientific concepts into large, billowing sculptures to generate beauty and wonder. Mystery is itself an entry point into both art and science. Each explore unknown realms to reveal truth and progress humanity.

When I first read about LIGO's discovery of gravitational waves from GW150914, something spoke deeply to me. The gorgeous numerical simulation by Alessandra Buonanno's group sparked my imagination. I wanted to learn about the elegant architecture of the nested curved surfaces. My curiosity has blossomed into an art and science collaboration.

Sarah Saulson, a handweaver of sublime, Jewish prayer shawls, introduced me to her husband, Peter Saulson, former LIGO Scientific Collaboration (LSC) Spokesperson. He agreed to present his one-hour lecture, "Listening to the Universe". However, it evolved into three months of virtual tutoring over the summer of 2020, due to my numerous questions and Peter's generous patience.

Understanding the basics of gravitational wave science dramatically launched my artwork into suspended sculptures. My newest piece, "Phase Evolution", imagines oscillating sinusoidal waves as dimensional rings that hover above a mysterious cosmic sphere. It is handwoven from wire and nylon, utilizing an ancient Peruvian weaving technique.

Currently, I am working on conceptual designs for a collaborative art installation, ideally for LIGO Hanford's new Exploration Center. How can kinetic sculptures merge with augmented reality to create an educational environment for gravitational wave astronomy?

To learn more, please visit:
www.AnastasiaAzure.com/GW

Anastasia Azure

creates art inspired by the elegance of science. Her three-dimensional sculptures are handwoven on a traditional floor loom. She enjoys climbing trees and meditating during sunset.

"Phase Evolution" by Anastasia Azure. Handwoven wire and nylon above a glass orb.

GR22 and Amaldi13 in Valencia

When the High Conservatory of Dance of Valencia (CSDV) received the proposal of participating in a congress of astrophysics with two performances (one in the Botanical Garden of the University of Valencia and another in the Museum of Science of the City of Science and Arts of Valencia), we had the challenge of connecting two aspects that we, dancers, do not know. In particular, aspects about time and space, with their expansions and contractions, which blow up our more lineal idea of these concepts. But, what is more characteristic to dance, precisely, than space and time? Is it not true that our movements are always gravitationally attracted to the floor and to our dance mates? Do we not manipulate our positions and movements to generate bodies which multiply and divide, join and separate, bodies which almost merge?

Getting away from literalism, a great group of students embarked on trying, improvising, selecting and closing a small piece in line with the proposal we received. And we do what we know best: let our bodies decide, navigate from ideas which finally end up taking form, becoming present from their complete abstraction. If science tries to provide an objective knowledge about everything around us, dance makes exactly the opposite: provides a subjective experience about what we all have inside us. In this contradiction, we get closer instead of further away, and complete the human experience, always looking for a meaning.

Participants: Gala Santamaría Máñez, Cristian Milego de Diego, Alba Galdón García, Mónica Vázquez, Ilya Gendler, Carmen Lozano Angulo, Marina Jiménez Guijarro, Noelia Sánchez Gómez, Laura Basterra Aparicio. Director: Santi de la Fuente (Professor of Contemporary Dance in the CSDV, Spain).[1]

Santi de la Fuente

has been professor of Technique and Composition at the Conservartori Superior de Dansa de València (High Conservatory of Dance of Valencia) since 2014. He co-directs the company 'La Coja Dansa' together with Tatiana Clavel.

[1] Translated by Isabel Cordero Carrión.

Samanwaya Mukherjee

and Kanchan Soni

are doctoral students at the Inter-University Centre for Astronomy & Astrophysics, India. Apart from his work, Samanwaya likes drawing, reading, writing and playing indoor games. In her free time, Kanchan enjoys making abstract art and playing the keyboard and chordophone.

Gravity Matters!

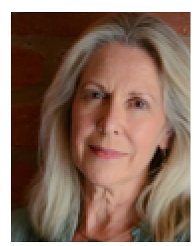
LIGO-India Education and Public Outreach recently launched an online blog "Gravity Matters" (see also p. 25). One of the components of the blog is the section "GW SciArt" - a virtual gallery for Gravitational Wave Science inspired art! The first article to be featured in this gallery is an acrostic poem called "Cosmic Whispers", whose initials spell out the word "LIGO INDIA". Poem by Samanwaya Mukherjee, artwork based on a doodle by Kanchan Soni.

The New Wave

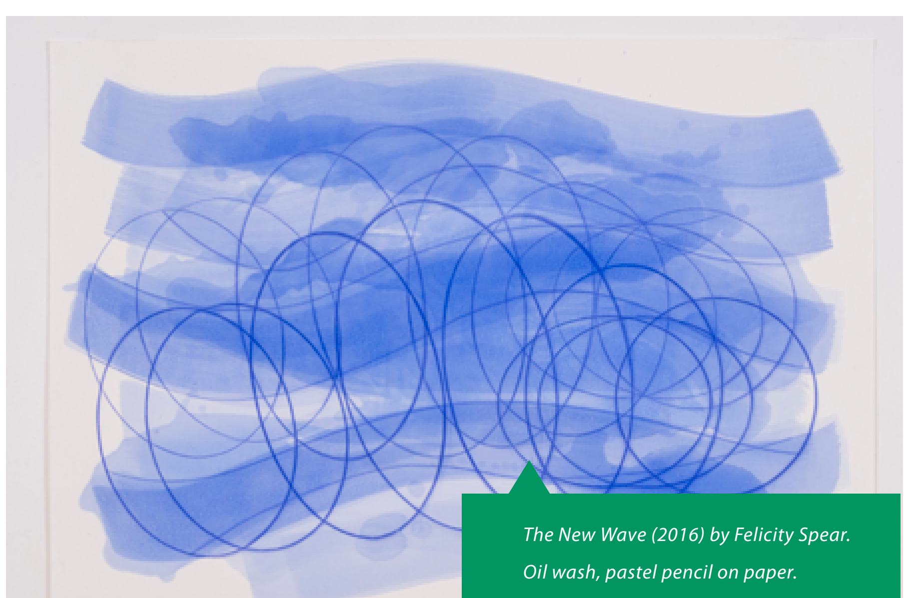
Felicity Spear's art practice focuses on the way in which we attempt to visualize, imagine and decode the physical world (much of it beyond the full range of our senses), in order to emphasize its value and complexity. Her work references the behaviour of light and the evolution of optics which emerged in 17th Century Netherlands, linking painting to the study of vision, while advancing the mapping of the cosmos and our understanding of space and time. During the International Year of Astronomy 2009, Spear curated the exhibition Beyond Visibility: Light and Dust, with pioneering astro-photographer David Malin, and celebrated indigenous artist Gulumbu Yunupingu. She has also curated a series of group exhibitions with the generic title Sky Lab and a number of solo exhibitions including Orbit- the Kepler Suite 2016. This suite of 10 mixed media works on paper was a homage to 17th century astronomer Johannes Kepler and his revolutionary theory, (still prescient today), of the elliptical orbits of planetary motion. These works were intended to give the viewer a sense of the hidden traces and forces which are embedded in the idea of 'orbit', while asking the viewer to think about mapping, space and light, geometry and physics, spheres and ellipses, atoms and particles, the push and pull of gravitational waves and distortions, and even the shape of our eyes.

Spear's PhD (2007 Monash University) was titled 'Extending Vision: Mapping Space in Light and Time.'

Felicity Spear



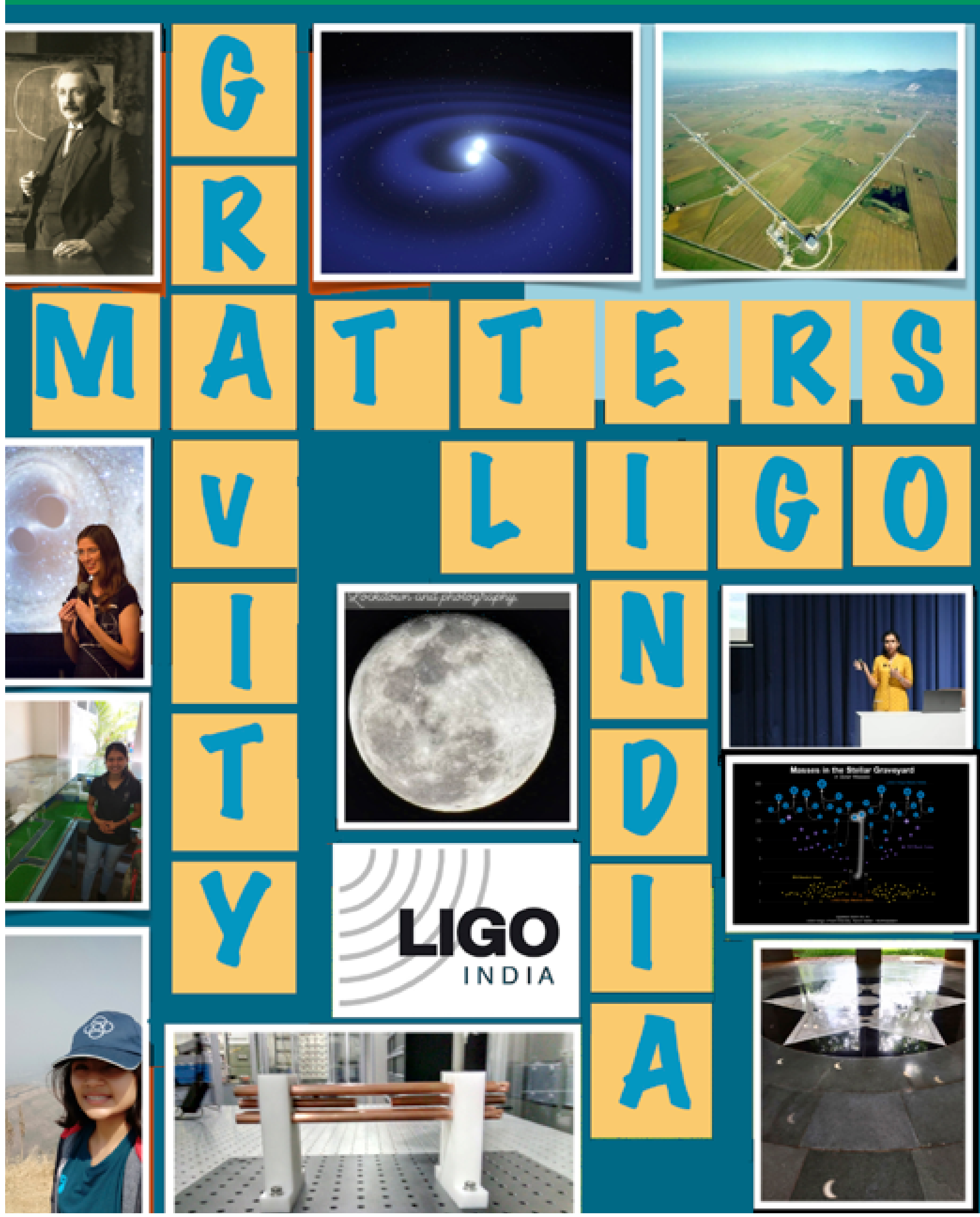
is a visual artist whose career spans teaching, making, curating and writing. She's a dedicated environmentalist, a Himalayan trekker, an observer of wildlife and science 'at a distance', a grandmother and a mentor. www.felicityspear.com



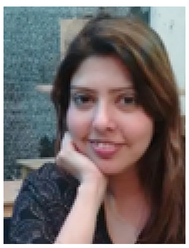
The New Wave (2016) by Felicity Spear. Oil wash, pastel pencil on paper.

Gravity Matters

A GW Science Blog from LIGO India



Debarati Chatterjee

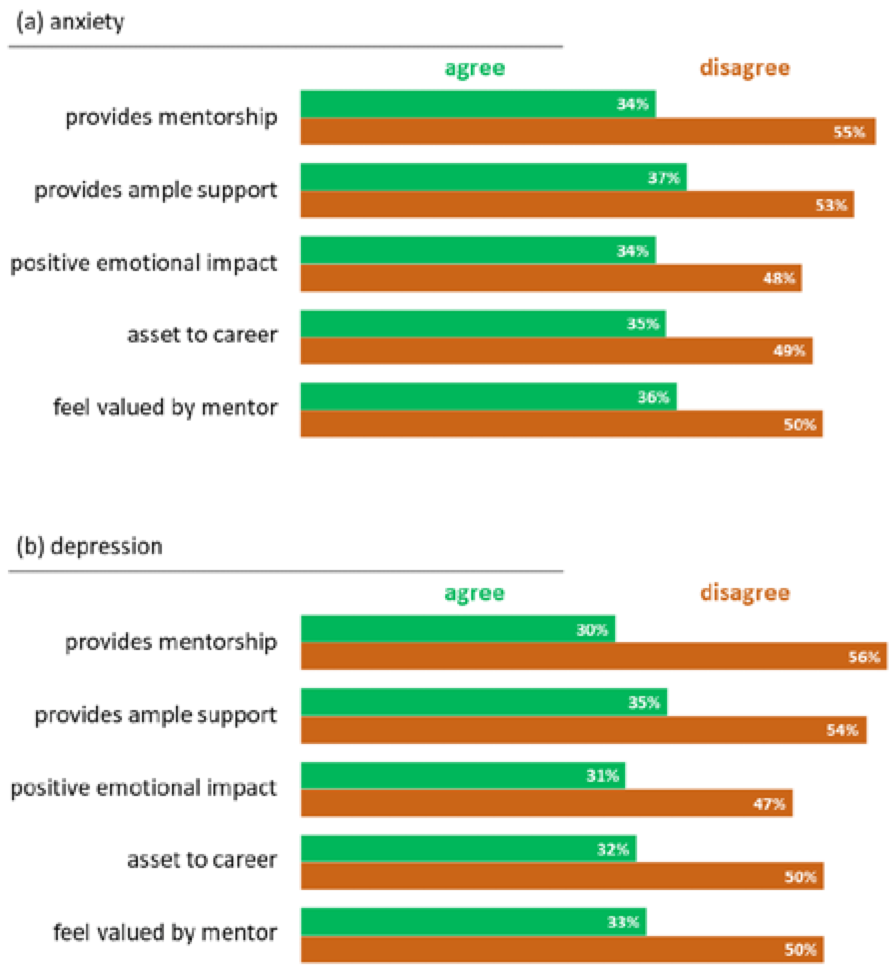


is the Chairperson of LIGO-India Outreach and creator/coordinator of the blog Gravity Matters. She is Associate Professor & faculty at the Inter-University Centre for Astronomy & Astrophysics, India

On the fifth anniversary of the first direct detection of Gravitational Waves GW150914, LIGO-India announced the launch of its Gravitational Wave (GW) Science blog "Gravity Matters". The main motivation of this blog is to provide a way to connect the young generation of GW Science enthusiasts from India, with scientists & experts across the globe, particularly during confinement in the face of the pandemic. This is an online venture primarily with contributions from students, for students, coordinated by the LIGO-India Education & Public Outreach team.

This blog has something for everyone. Students will not only get a chance to learn about the detection events & the GW Science behind it from the frontiers of research in the section "LIGO-India Science", but also about the interdisciplinary fields associated with it: Gravitation, Compact Star physics, Numerical Relativity, GW Instrument Science, Electro-Magnetic counterparts and Multi-messenger astronomy. An exciting component of the blog is the GW Podcast "Listening to the Cosmos", which features short interviews with researchers from all over the world. To motivate young girls to take up GW Science, there is a segment "Glorious Women in Astronomy" where women scientists contributing to this field are regularly featured. The articles on the "Storyboard" cover miscellaneous topics to pique one's interest. "Behind the Scenes" will present snapshots from the daily lives of the student researchers. Recently, a new section "GW SciArt" was also introduced - a virtual gallery for GW Science inspired art. Interested students can also follow the latest announcements about upcoming LIGO-India events and diverse internship opportunities here. Soon, there are plans to include a photo quiz "Guess What", comic strips and much more! There is also a teaser video on the blog for a quick preview. Log on to www.ligo-india.in/gravitymatters or keep an eye on the LIGO-India social media pages for exciting news from the world of GW Science!

Building Towards Healthy Supervision



Effect of the reported level of support and the relationship with the supervisor on people experiencing anxiety (a) and people experiencing feelings of depression (b). Data taken from [2].

We probably all agree that good academic supervision is essential - but what does 'good supervision' actually mean? And why is it so important? While the answer to the first question may be quite individual, the second one is easily answered: it is critical for your scientific output; it is important for your career development (in particular if, at some point, you end up in the position of supervising other people yourself); and it is also very important for your mental health. With the ongoing measures to fight the pandemic placing additional strain on everyone's mental health, this topic becomes even more relevant.

"What is the interplay between good supervision and one's mental health?"

Being an early career scientist can be challenging. The academic environment is competitive, sometimes with tight deadlines. You may face job insecurity or the need to move abroad to find a suitable position. Furthermore, being in a large collaboration can give you more social support, but at the same time there is also a large administrative burden.

Several studies have shown that early career scientists experience exhaustion[*] with numbers often reaching 25% [1] and up to 40% report experiencing feelings of anxiety and/or depression [2].

[*] 'exhaustion': a chronic state of emotional depletion and fatigue

Kamiel Janssens

is a PhD student in Antwerp, Belgium and a member of Virgo. He searches for a stochastic gravitational wave background and contributes to environmental noise monitoring. In his free time he likes rock climbing and learning more about psychology and mental health issues.

Further reading and bonus content on p.35

Bonus content on p.35

Sometimes exposure to high stress levels at work can lead to a burnout, a state of exhaustion and cynicism[†].

Research has shown that there is an interplay between one's supervision and one's mental health [1,2]. As shown in the figure 1 (*see prev. page*) people who report experiencing feelings of anxiety/depression also report feeling less satisfied with their supervision [2]. Furthermore PhD students with poor supervision can suffer from larger levels of stress, exhaustion and cynicism compared to other PhD students [1]. They are not only more prone to getting burnout, but are also more likely to drop out of their PhD program [1].

It is also good to be aware we are part of a large international collaboration and in different countries there are different structures present which might affect your scientific career, experienced stress levels and so on, where an obvious difference might be the duration of your PhD. This might give you a more nuanced understanding of what to expect of yourself and what barriers you may encounter. It is in our human nature to compare ourselves with our peers, but be kind and mild to yourself.

Creating a supportive and favorable environment will not only positively affect the mental health of the early career scientist, but also their overall scientific output.

“How can I improve my supervision and the relationship with my supervisor?”

First of all it is a good idea to try and build a ‘circle of trust’ around you, with whom you can share your thoughts or struggles when you experience tough times during your PhD or after. They can be colleagues or a mentor[§]. At the same time you are increasing your network of potential future collaborators: win-win! Once conferences are back in person, social events are also the perfect place to connect with other scientists from all over the world.

It is a good idea to have regular meetings with your supervisor(s). If they don’t schedule meetings, don’t be afraid to ask for it yourself! Preferably this would be at least once a month. This is the perfect moment to set research or career targets together and discuss progress towards these targets. These meetings are complementary to more regular ‘working meetings’. Instead of discussing practical issues you can discuss what goes well and what doesn’t. It is not about evaluation but about functioning: how you both can grow and learn in your function as a young scientist or supervisor. Yes you read it correctly, this open discussion should go both ways!

If you are a supervisor yourself and you read this, be aware it isn’t always easy for young scientists to make the first move. Be proactive yourself and check in with your PhD students/postdocs. Furthermore it is important to realise that everyone is a unique individual and this implies that something that has worked for you in the past, might be a struggle for someone else.

As an early career scientist it might sometimes be hard to have a clear picture of your targets, since, especially when you start, many of the goals might be vague and far away in the future. This might decrease your work effectiveness due to suboptimal planning. Furthermore reaching targets gives a sense of accomplishment and satisfaction, bolstering one’s defense against high levels of exhaustion or a burnout.

Therefore it is a good idea to set clear and realistic targets together with your supervisor both on short and long time scales. Long term goals could for instance be the different papers you will try to publish during the course of your PhD/postdoc. Shorter term targets could be learning a new technique/program, taking part in some onsite work or just several intermediate stages of your analysis.

Upon reaching your goals, take a moment to realize your accomplishment and give yourself some value for it!

Supervision can not only have an impact on one’s scientific output but also on one’s mental health. Therefore we encourage both supervisor and early career researcher to continuously work on their relationship.

If you are interested in learning more about these topics, we’ve listed some further reading [see p. 35]. You might also consider reaching out to your institution's counselling and wellbeing services for support, or your collaboration’s ombudsperson(s) for help with managing interactions or interpersonal conflicts.

References

[1] Cornér S., Löfström E. and Pyhältö K., The Relationships between Doctoral Students’ Perceptions of Supervision and Burnout, International Journal of Doctoral Studies 12, 91-106 (2017). https://doi.org/10.28945/3754

[2] Evans, T., Bira, L., Gastelum, J. et al. Evidence for a mental health crisis in graduate education. Nat Biotechnol 36, 282–284 (2018). https://doi.org/10.1038/nbt.4089

[†] ‘cynicism’: a detached response to colleagues and work

[§] To sign up for a LAAC mentor visit laac.docs.ligo.org/project/mentoring
The Virgo Early Career Scientist (VECS) group program: wiki.virgo-gw.eu/VirgoCollaboration/VirgoEarlyCareerScientists/Mentoring

Craig Ingram: Imaging the Earth with CubeSats

Craig Ingram is a senior optical engineer at the University of Adelaide CSIRO.
craig.ingram@adelaide.edu.au

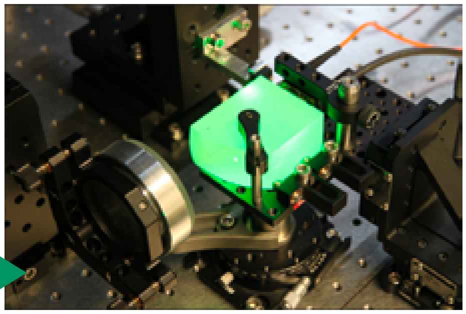
When I returned to study after working as a photographer for nearly twenty years, it was with the intention to teach high school maths and physics students. However, I was introduced to the world of research when I got offered a master's position within the Adelaide node of the ARC Centre of Excellence for Gravitational Wave Discovery (OzGrav). This was an opportunity I could not let pass. I could always return to teaching if research wasn't my thing, but I have never looked back. Working in the LIGO collaboration on such a groundbreaking project was an amazing introduction to the world of research and one that I will be forever grateful for.

After completing my masters, I was offered a position as a visiting researcher at the Commonwealth Scientific and Industrial Research Organisation (CSIRO). CSIRO is an Australian government research agency with many notable developments to its name including the invention of atomic absorption spectroscopy, essential components of the Wi-Fi technology and the development of the first commercially successful polymer banknote. It was also at the CSIRO facility in Sydney where the LIGO mirrors were coated. However, my journey in gravitational waves has come to an end as I will now be looking back at earth rather than looking out.

I currently work as a lead optical engineer developing hyperspectral imager, which allows us to obtain a spectrum for every pixel in an image, with the purpose of finding objects, identifying materials, or detecting processes otherwise hidden with standard imaging. Currently, most hyperspectral imagers are deployed in medium to large satellites, think of a washing machine sized instrument and larger. We are trying to develop smaller instruments to be flown in CubeSats (miniature satellites that are made up of multiples of 10x10x10 cm units) while maintaining the resolution of these larger devices. In our case, this shoebox size satellite will house an imager, telescope, electronics and communication equipment along with all of the apparatus required to keep the satellite in space and orientated correctly. As you can imagine, this brings up some unique challenges.

We are utilising the knowledge and capabilities of CSIRO and the Institute of Photonics and Advanced Sensing (IPAS) at Adelaide University such as 3D printed Invar to create unique designs to be able to cope with the size constraints and the extreme conditions encountered in low earth orbit.

The project is going from strength to strength with new collaborators and partners coming on board as we progress through design and testing. Although we currently have only eight people working on this project, we are aiming high. Our first test flight will be done with a drone and will be followed by the first test of our instrument in space-like conditions in a high-altitude platform to be launched in a few week's time (at the time of writing). At an altitude of over 30 km, we should get a fantastic opportunity to test the system in a space-like environment. So, fingers crossed we get some great data and our imager returns to earth in one piece.



Tolerancing the Dyson Spectrometer. The Dyson Imaging Spectrometer is a simple, compact design consisting of a concave diffraction grating and a concentric element, here illuminated green, used to minimize aberrations. The current 1U design has a resolution better than 5 nanometers.

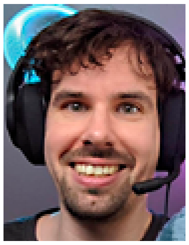
LISA Symposium - The Next Generation

The 13th International LISA Symposium goes online.

Every two years the larger gravitational-wave community comes together at an international Symposium to discuss research related to LISA, the Laser Interferometer Space Antenna - an observatory capable of detecting much lower frequency gravitational waves than possible with ground-based facilities. It was early in 2020 when it became clear that the planned venue in Glasgow would have to be postponed. So the 13th International LISA Symposium did boldly go where so many conferences had to go last year: online only.

In order to keep the Symposium free of charge and open it up to a wider audience, we created a custom open source online platform with in-house resources and volunteers. Users were able to register, add research interests, and submit applications for pre-recorded talks. The newly formed organizing committee screened over 200 abstracts and created a collection of virtual conference rooms for topics reaching from cosmology and observations to education. Most talks are still available online and visitors can ask questions or connect directly with the presenters. Our platform offers an easy-to-search participant database with message board functionality, a job market, and comment sections for each presentation. In a way, we replaced conference proceedings by an on-demand conference that you can visit anytime you want.

Simon Barke



has been involved with the LISA mission since 2008 and is currently working on the Charge Management System at the University of Florida. Simon enjoys app and web development and has created the LISA Symposium XIII platform with a Vue.js based JavaScript framework on Google Firebase.

The very same web platform hosted a 3-day, 4-hours-per-day live conference that featured a young and diverse group of presenters. Plenary talks, with topics ranging from multi-messenger astronomy and data analysis to fundamental physics and instrumentation, were presented by Nick Stone, Ewan Fitzsimons, Sachiko Kuroyanagi, Mansi Kasliwal, Stas Babak, Sweta Shah, Helvi Witek, Jenny Greene, and Valeriya Korol. The agenda was rounded up by parallel sessions, town halls, topical discussion sessions, and a Diversity, Equity, and Inclusion training session. Seven graduate students helped to produce and coordinate the over 30 live events with great success.

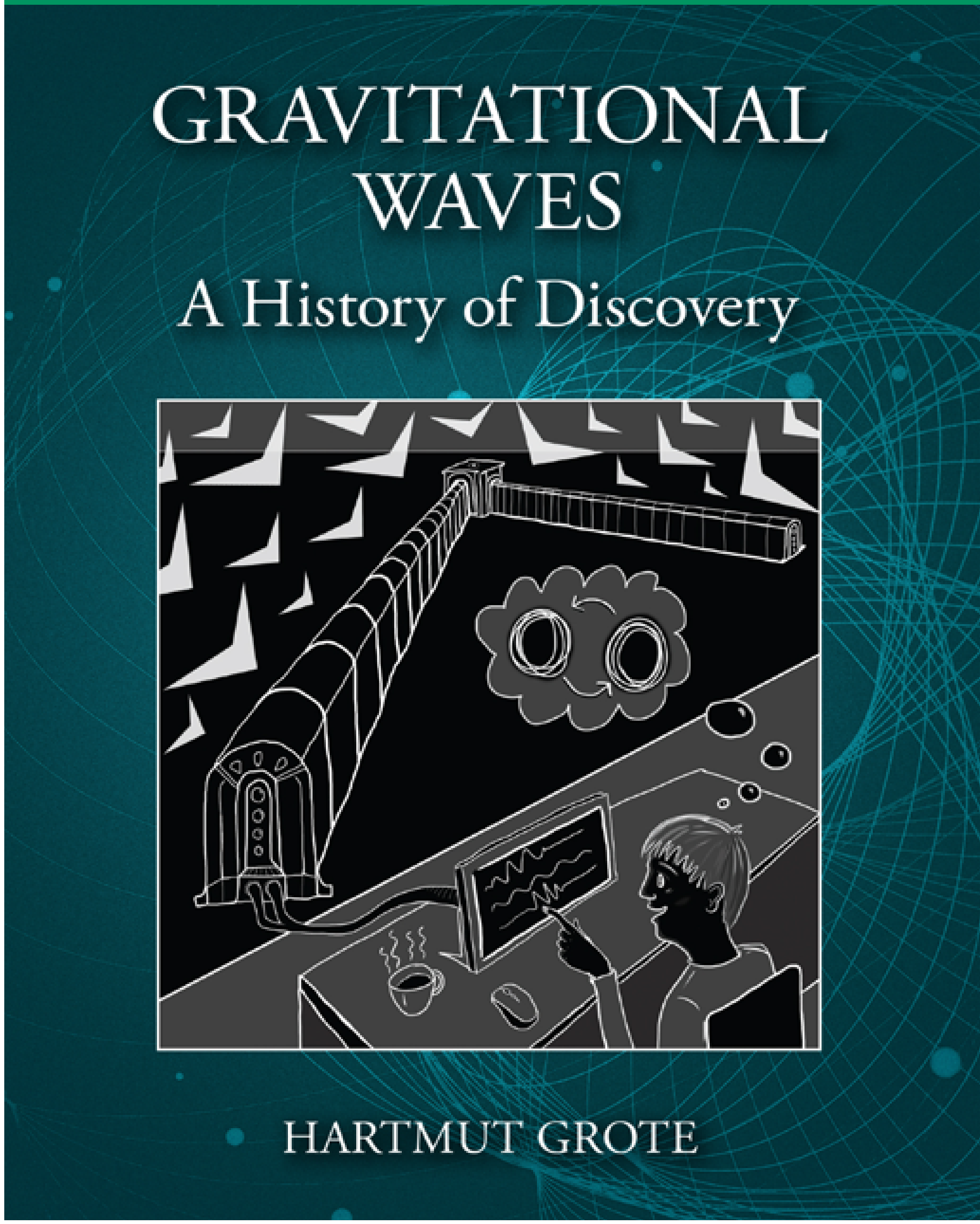
The Symposium attracted 1100 participants from all over the world—more than three times the attendance of the largest LISA face-to-face meeting so far. Feedback was overwhelmingly positive. In a survey among attendees, almost 90% of respondents supported the addition of online live video feeds and pre-recorded talks to upcoming in-person meetings. Such a change will give a voice to researchers who might otherwise be unable to travel to expensive face-to-face meetings. And hopefully this will generate many more rich libraries of publicly available talks in the future.

You can revisit the 13th International LISA Symposium at https://lisasymposium13.lisamission.org and check out the full list of organizers.

Watch the symposium video talks here:
https://lisasymposium13.lisamission.org/agenda/highlights
https://lisasymposium13.lisamission.org/agenda/prerecorded

We also reported about the LISA Symposium in the AAS High Energy Astrophysics Division newsletter.

Gravitational Waves: A History of Discovery



With the demands of research, teaching, and a toddler at home (whose energy levels seem to violate at least one conservation law), I must admit that these days it's hard to find the time to sit down with a good book and read it cover to cover. So when I was asked in my capacity as a LIGO Magazine editor to find someone to review Hartmut Grote's book Gravitational Waves: a History of Discovery I cheerfully volunteered myself to do it, seizing the opportunity to call a good reading session "work". I'm certainly glad I did, because reading this book was indeed a pleasure. Although I suspect I'm not in the primary target audience for this accessible synopsis of gravitational wave history, I found the book to be an engrossing read full of interesting tidbits even for someone who has been working in the field for 15 years.

For those of you who don't already know Hartmut, he is a venerated veteran experimentalist, who for many years led the development of new technologies at GEO600 such as squeezed light enhanced laser interferometry. He now holds a faculty position at Cardiff University, and his years of experience at the forefront of this field put him in an ideal position to write a book about the history of gravitational wave detection.

The book begins with the history of the theoretical prediction of gravitational waves, from Newton's concern over the instantaneous propagation of the gravitational force in his theory, through to Einstein's development of General Relativity and the appearance of the wave solution to his field equations. Dr. Grote then takes us through the early years of the experimental search for these waves, following the work and controversial claims of Joseph Weber and the many groups who built resonant bar detectors in attempt to replicate his disputed results. The story continues with the development of laser interferometers, from the prototype detectors to the full scale interferometers in locations spanning the globe. Along the way the author explains the technologies that enable the detectors to reach their incredible sensitivities. Hartmut then gives an overview of how data analysis is performed, and describes the famous "Big Dog" blind injection of 2010. The story of course climaxes with the groundbreaking detection of GW150914 and subsequent events, but finishes on a forward looking note with a discussion of planned 3rd generation interferometers, as well as space-based detectors and pulsar timing arrays.

The style of the writing is refreshingly clean and precise, giving intuitive explanations of complex concepts that underpin the field, without getting bogged down in the details. That's not to say that Hartmut glosses over the complexities entirely – he simply explains what's necessary to understand the history of the field, and makes judicious choices on where to leave the reader to pursue the intricacies further by themselves. For example, it must have been tempting for the author to launch into a long and comprehensive description of squeezed light generation and utilization in GEO600, that might have flown over the head of the casual reader. Instead, Hartmut wisely keeps the discussion to a breezy two paragraphs while merely hinting at the underlying complexity.

It would be remiss of me not to make note of the charming illustrations dotted throughout the book (provided by Josh Field) which add a whimsical counterbalance to the more serious scientific content. The front cover in particular gives a wonderfully ingenuous depiction of the whole business of gravitational wave detection, from the astrophysical source, through the laser interferometer, to the computer display and the scientist viewing it.

Paul Fulda

is an Assistant Professor of Experimental Astrophysics at University of Florida, where he works on LIGO and LISA instrument science. When he isn't fiddling about with lasers he likes to go gator spotting with his family, brew (and drink) beer, skateboard and play music.

If there is one thing that I was left wanting more of after reading this book, it would be a deeper dive into the author's own personal experiences from working in the field. After all, Dr. Grote himself has been at the forefront of interferometer technology development for several decades, and I'm sure he has a treasure trove of interesting stories of his own to tell. Perhaps this falls outside the scope of the historical work in question, and may instead be something more for the hardcore laser-nerds like myself. I'll keep my eyes peeled in the future nonetheless, in the hopes that Hartmut some day feels the urge to pen a second volume.

Hartmut Grote

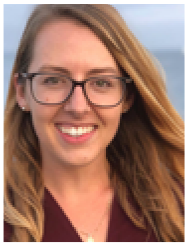
I would strongly recommend this book to new students joining the field, for two main reasons. First of all, because it gives a good historical context to several of the quirks of our field (such as the reason for the long delay between detection and publication of GW150914). Secondly, because this book covers the broad spectrum of research in the collaboration, from the fundamental noise sources limiting the detectors, to the data analysis techniques we use and the astrophysics and cosmology we probe with our measurements. New students typically specialize in one of these areas very quickly, so reading a book like this will be a good way to understand the concepts (if not the details and math) that form the foundations for areas outside that specialism.

This book would also be a great read for friends and family members of researchers in the collaboration. Being accessible to those not already familiar with the field, it would give them a better understanding of what it is their friend/family member does all day, and perhaps also why we do it! Of course the book may also find an enthusiastic readership among the general science-interested public, who I hope will find it as I did, to be an engaging and thought provoking read.

A discovery in the dark

César Rojas-Bravo at the Swope telescope in Chile.

Lara Streiff



writes for the Earth Science News team at NASA's Goddard Space Flight Center in Greenbelt, Maryland and is a graduate of the UC Santa Cruz Science Communication program. She lives with roommates in San Francisco where she bakes sourdough regularly.

Though we were both at the University of California, Santa Cruz, César Rojas-Bravo and I never met after COVID-19 pandemic restrictions took effect. Instead we connected over social media, Skype and email. His humble nature, musings over classical languages, and inspiration from the likes of J.R.R. Tolkien and Costa Rican astronaut Dr. Franklin Chang Diaz, made for genuinely enjoyable conversations – yet it was his unique story of discovery that I felt had to be told.

In June 2017, César Rojas-Bravo left Costa Rica a couple of months early to ease his transition into graduate school in the United States. Instead, he was thrown into a whirlwind discovery that most scientists only ever dream of.

Rojas-Bravo joined a young group of astronomers referred to as the "Swope Team", named for the eponymous telescope in Chile. Led by Ryan Foley, a new astrophysics professor at the University of California, Santa Cruz (UCSC), they were attempting to observe a spectacular phenomenon.

Gravitational waves had been detected by the LIGO and Virgo Collaborations from the merger of two neutrons stars. This event (GW170817) sparked a race among numerous scientific teams to spot and photograph light from the resulting kilonova, a phenomenon never observed before. On the night of August 17th 2017, researchers across the globe turned telescopes in its direction hoping to catch a glimpse.

A chaotic energy consumed that night as images first started coming from the Swope telescope. Rojas-Bravo took a seat and started processing the images, but found himself at a slight disadvantage: no one had told him what they were looking for. The timing of his arrival meant that, unlike the rest of the researchers, Rojas-Bravo was not covered by a memorandum of understanding (MOU) to keep the details of the neutron star collision under wraps, so he was kept somewhat in the dark. "I'm sure he figured it out, I'm sure he knew what was going on," Foley says. "He played a key role even though he had one hand tied behind his back." Indeed Rojas-Bravo had a good idea of what was happening. "I was in the room working like crazy, I was yelling 'The first image is processed! The second! The third one!'" Eventually Charles Kilpatrick, a postdoc on the team sitting just behind Rojas-Bravo, went silent. "That's the moment when [Kilpatrick] saw the actual kilonova, but then he was so busy he didn't have time to explain."

The stars had indeed aligned: Foley's team was the first to photograph the kilonova and to announce their findings. The discovery swept them into an overwhelming media wave. It was the first time that astronomers had seen light and gravitational waves produced by the same event. Science named the discovery the 2017 Breakthrough of the Year.

"It was probably the biggest scientific discovery that we will ever make in our lifetime," Rojas-Bravo says as he swings his left hand above his head toward the ceiling. "From there it's hard to go...beyond that."

Now Rojas-Bravo hunches over his laptop in his childhood bedroom in Alajuela, Costa Rica. Football club posters from Catalonia and Turkey adorn one wall. He wears a red-and-black striped football jersey from his city's home team in Costa Rica, with his shoulder-length hair pulled into a loose ponytail, and sifts through data sets in this makeshift office due to the COVID-19 pandemic.

One day he hopes to move back to Costa Rica permanently to teach the next generation of astronomers. "There's a term in Spanish for when people study abroad and remain abroad for the rest of their life: 'Fuga de cerebros'" which roughly translates to "brain drain". "It's like the country doesn't get back what they gave them." Rojas-Bravo says. "I definitely don't want to do that. I want to give back to the country what they gave me."

The Universidad de Costa Rica doesn't offer a bachelor's degree in Astronomy, so Rojas-Bravo studied physics instead. "I just didn't know it was possible to become an astronomer, at least in Costa Rica," he said. But learning of Costa Rican NASA Astronaut Franklin Chang Diaz offered a glimmer of hope.

In 2015, Rojas-Bravo attended the ICTP - SAIFR* research school of gravitational waves and astrophysics in Brazil. There he met Enrico Ramírez-Ruiz, professor and former chair of the UCSC Astronomy & Astrophysics Department. Coincidentally, Ramirez-Ruiz gave a talk about the possibility of observing a kilonova in upcoming years, and eventually led Rojas-Bravo to find the Ph.D. program in Santa Cruz and apply to it the following year. "I was completely in awe of how much he was respected by everyone in the school—how someone from Latin America, as myself, was so successful and at the same time so down-to-earth," Rojas-Bravo says.

Ramírez-Ruiz was similarly impressed. "[Rojas-Bravo] immediately stood out as one of the strongest students in the school, but he did it with grace and empathy," Ramírez-Ruiz says. "That sort of kindness, and inquisitive mind, is unusual."

It was Ramírez-Ruiz who connected Rojas-Bravo with Foley, who in turn planned for his travel to Santa Cruz in the Summer of 2017 – mere months before the Ph.D. program officially started. "César was clearly incredibly eager to work," Foley says. "He's also really, really smart. It does make a difference if you have the brains to back up all the other stuff, and he does."

Since then, Rojas-Bravo has visited the famed telescope in the Atacama Desert, spending several nights in the Las Campanas Observatory as images of stars millions of light years from Earth are sent on to his office back in Santa Cruz. The desert's howling winds drown out all other sounds as they twist through the dry hills, upon which several other white domed telescopes perch. It's shockingly different from the lush green surroundings of his home country.

During breaks, he'd pull on a jacket and walk outside into the dark arid landscape, peering up at the same star-studded night sky – this time with just his eyes.

"Not even in my wildest dreams, I dreamt of going to Chile to observe with a telescope," Rojas-Bravo says. "It feels very surreal."

LIGO 2021

Swope observation of SSS17a, the optical counterpart to gravitational wave source GW170817. The arrow shows the position of SSS17a in its galaxy NGC 4993.

[†] International Center for Theoretical Physics's South American Institute for Fundamental Research (https://www.ictp-saifr.org/)

Career Updates

Amber Stuver has been elected to the APS Forum Education executive board as a Member-at-Large. She has also been appointed to the AAS Committee for the Status of Women in Astronomy.

Corey Austin has graduated with his PhD from LSU and taken a job at NASA.

James Clark now works for the LIGO laboratory in a computational scientist position. James remains based in Atlanta in a similar LIGO grid computing & data management role as previously.

Keiko Kokeyama began a new position as a faculty member at Cardiff University in January 2021.

TJ O'Hanlon and **Karla Ramirez** have recently been welcomed to the team at LIGO Livingston Observatory, where they will work as operators of the L1 detector.

Susan Scott was elected a 2020 Fellow of the American Physical Society

Awards

David Blair, David McClelland, Susan Scott, and **Peter Veitch** were awarded the 2020 Australian Prime Minister's Prize for Science.

Bangalore Sathyaprakash received the IIT Madras's Distinguished Alumni Award 2021.

Chris Messenger has won the Win-A-Lab competition, providing funding that will enable him to develop a General Relativity teaching tool using Virtual Reality.

Dripta Bhattacharjee and **Yanyan Zheng,** Ph.D. students in physics and @imac_SandT researchers, won a Women in Physics Group Grant from the American Physical Society to establish a Women in Physics group at Missouri S&T.

Jade Powell was awarded an Australian Research Council Discovery Early Career Researcher Award (DECRA) for her project titled "Exploding massive stars and their implications for gravitational waves".

Juan Calderón Bustillo, former Research Assistant Professor at The Chinese University of Hong Kong received a La Caixa Junior Leader - Marie Curie Fellowship which he has brought to the Galician Institute of High Energy Physics of the University of Santiago de Compostela

Marina Trad Nery received the Prize of the Leibniz Universitätsgesellschaft e. V. for her outstanding research in the field of quantum optomechanics, and her involvement in the EU-funded Marie Curie International Training Network "GraWiToN", which supported her PhD studies at the institute and at the Leibniz University with a fellowship. https://www.aei.mpg.de/611117/preis-der-leibniz-universitaetsgesellschaft-e-v-fuer-dr-marina-trad-nery

Parameswaran Ajith was awarded the inaugural TWAS-CAS Young Scientist Award for Frontier Science in the Physical Sciences, by the Italy-based World Academy of Sciences.

Prof. **Alessandra Buonanno** was awarded the biennial Galileo Galilei Medal by the Italian National Institute for Nuclear Physics (INFN) in collaboration with its National Center for Advanced Studies, Galileo Galilei Institute (GGI) in Florence. Other awardees this year were Prof. **Thibault Damour** (Institut des Hautes Études Scientifiques) and Prof. **Frans Pretorius** (Princeton University). https://www.aei.mpg.de/636770/Galileo-Galilei-Medal-for-Alessandra-Buonanno

Physical Review D selected two papers by **Alessandra Buonanno** and **Thibault Damour** for its "50th anniversary milestones". Two publications from 1999 and 2000 authored by Alessandra Buonanno and Thibault Damour are among those selected, as well as two papers on GW150914, the first direct detection of gravitational waves in 2015.

Susan Scott was awarded the 2020 Dirac Medal and Lecture, an international award by the University of New South Wales for distinguished contributions to theoretical physics.

Vitali Müller will receive one of the eight biennial 2020 Zeldovich Medals awarded by the international Committee on Space Research (COSPAR) for his work in the field of interferometry between satellites and its applications.

New LSC positions

In LAAC (LIGO Academic Advisory Council), **Graeme Ian McGhee** was elected as graduate student representative, **Huy-Tuong Cao** was elected as postdoctoral representative, **Jessica Steinlechner** was re-elected as co-chair, and **John Veitch** was elected as senior member.

Sheila Rowan has been elected as echnical Advisor to the LIGO Oversight Committee.

Other News

GEO600 has achieved 6dB of squeezing. This is the strongest squeezing in a gravitational-wave detector and represents a big step towards third-generation detector such as the Einstein Telescope and Cosmic Explorer. https://www.aei.mpg.de/626965/geo600-reaches-6-db-of-squeezing

The **CSIRO Parkes 64m radio telescope** has been honoured with a traditional name chosen by **Wiradjuri Elders**. The name **Murriyang** was revealed at a local naming ceremony during NAIDOC week in November 2020. Two smaller telescopes at the Parkes Observatory also received Wiradjuri names: Giyalung Miil, for the 12-metre ASKAP testing antenna and Giyalung Guluman, for the 18-metre decommissioned antenna. https://www.csiro.au/en/News/News-releases/2020/CSIROs-iconic-Parkes-radio-telescope-given-Indigenous-name

/ Bonus content

Further Reading:

- The Good Supervision Guide for new and experienced research supervisors of PhDs, Bulat A., UCL (2019) https://www.ucl.ac.uk/teaching-learning/publications/2019/aug/good-supervision-guide-new-and-experienced-research-supervisors-phds
- 7 Ways PhD Students And Academics Can Deal With Stress, Anxiety And Depression, Sorbara C., CheekyScientist.com (2015) https://cheekyscientist.com/7-ways-phd-students-academics-deal-stress-anxiety-depression/
- PhD Mental Health: The importance of self-care during the writing process, Mavralidija, ThePhDProofReaders.com (2019) https://www.thephdproofreaders.com/writing/phd-mental-health/

Communication is essential between student and professor

We probably all agree that good academic supervision is essential - but what does 'good supervision' actually mean? And why is it so important? Read the article on pp. 26-27 to learn about the answer.

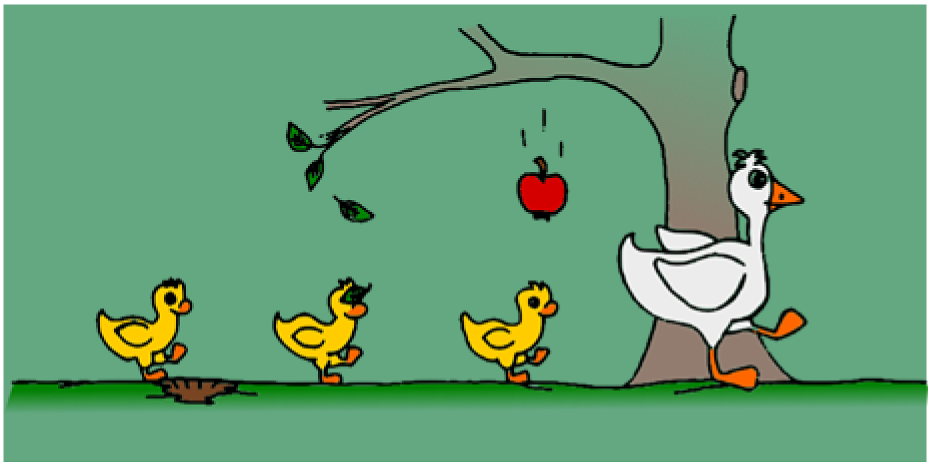
LIGO is funded by the National Science Foundation and operated by the California Institute of Technology and Massachusetts Institute of Technology. This material is based upon work supported, in part, by the National Science Foundation. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

The authors gratefully acknowledge the support of the United States National Science Foundation (NSF) for the construction and operation of the LIGO Laboratory and Advanced LIGO as well as the Science and Technology Facilities Council (STFC) of the United Kingdom, the Max-Planck-Society (MPS), and the State of Niedersachsen/Germany for support of the construction of Advanced LIGO and construction and operation of the GEO600 detector. Additional support for Advanced LIGO was provided by the Australian Research Council. The authors gratefully acknowledge the Italian Istituto Nazionale di Fisica Nucleare (INFN), the French Centre National de la Recherche Scientifique (CNRS) and the Netherlands Organization for Scientific Research, for the construction and operation of the Virgo detector and the creation and support of the EGO consortium. The authors also gratefully acknowledge research support from these agencies as well as by the Council of Scientific and Industrial Research of India, the Department of Science and Technology, India, the Science & Engineering Research Board (SERB), India, the Ministry of Human Resource Development, India, the Spanish Agencia Estatal de Investigación, the Vicepresidència i Conselleria d'Innovació, Recerca i Turisme and the Conselleria d'Educació i Universitat del Govern de les Illes Balears, the Conselleria d'Innovació, Universitats, Ciència i Societat Digital de la Generalitat Valenciana and the CERCA Programme Generalitat de Catalunya, Spain, the National Science Centre of Poland and the Foundation for Polish Science (FNP), the Swiss National Science Foundation (SNSF), the Russian Foundation for Basic Research, the Russian Science Foundation, the European Commission, the European Regional Development Funds (ERDF), the Royal Society, the Scottish Funding Council, the Scottish Universities Physics Alliance, the Hungarian Scientific Research Fund (OTKA), the French Lyon Institute of Origins (LIO), the Belgian Fonds de la Recherche Scientifique (FRS-FNRS), Actions de Recherche Concertes (ARC) and Fonds Wetenschappelijk Onderzoek Vlaanderen (FWO), Belgium, the Paris Île-de-France Region, the National Research, Development and Innovation Office Hungary (NKFIH), the National Research Foundation of Korea, the Natural Science and Engineering Research Council Canada, Canadian Foundation for Innovation (CFI), the Brazilian Ministry of Science, Technology, and Innovations, the International Center for Theoretical Physics South American Institute for Fundamental Research (ICTP-SAIFR), the Research Grants Council of Hong Kong, the National Natural Science Foundation of China (NSFC), the Leverhulme Trust, the Research Corporation, the Ministry of Science and Technology (MOST), Taiwan, the United States Department of Energy, and the Kavli Foundation. The authors gratefully acknowledge the support of the NSF, STFC, INFN and CNRS for provision of computational resources.

Online ISSN: 2169-4443
World Wide Web URL: https://www.ligo.org/magazine
Publisher: LIGO Scientific Collaboration, Pasadena, CA, USA
LIGO DCC: LIGO-P2100085
Contact: magazine@ligo.org

Design & production: Milde Marketing International Science Communication + formgeber
Printed by GS Druck und Medien GmbH Potsdam

Supported by the Max Planck Institute for Gravitational Physics (Albert Einstein Institute/AEI), and the California Institute for Technology (Caltech)



LAAC CORNER

The LIGO Magazine is printed on certified sustainable paper.

How it works: Hunting a stochastic gravitational wave background

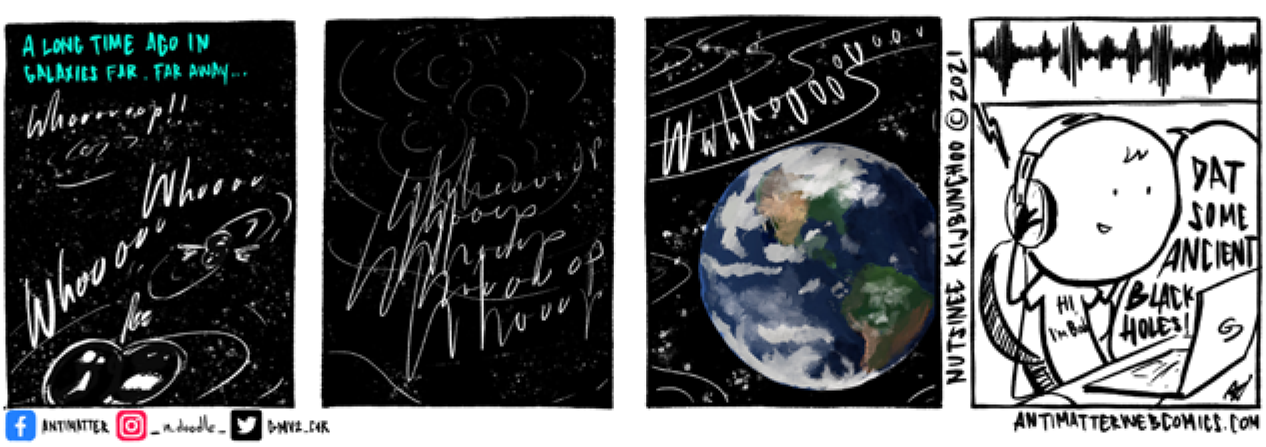
We have heard about the LIGO and Virgo detections of binary black hole, binary neutron star, and neutron-star black hole mergers. These signals last a few milliseconds to a minute, and the signal is close to, or larger than, the detector noise. If we look at longer stretches of data, we could detect even weaker signals that are emitting constantly.

For example, we could detect a signal from all the compact binary mergers we can't see individually, and perhaps even a signal generated in the early Universe! This signal is the stochastic gravitational-wave background (SGWB).

One potential source of a SGWB could be unresolved compact binary mergers. Individual compact binary mergers have a characteristic "chirp". However, if they start to overlap and we cannot pick out individual chirps, then their collective signal will look like many random sine waves added together.

One of the leading theories that describes the big bang is inflation. In this theory, the universe undergoes exponential expansion in its early stages. Some theories of inflation result in gravitational wave production, which someday we could observe directly. This is earlier than probes of the Universe we have now, like the cosmic microwave background, which was produced about 300,000 years after the big bang.

To detect a SGWB we cross-correlate data from different detectors. We can't use normal "matched-filtering" techniques, where we compare an expected signal to the data, because the SGWB is the sum of many signals combined together. If the cross-correlation between the detectors is larger than we expect for pure noise, then we say we've detected a SGWB.



LIGO 2021

 by Pat Meyers, illustration by Nutsinee Kijbunchoo