LIGO Scientific Collaboration

issue 17 9/2020

LIGO MAGAZINE

LIGO in Lockdown

p.6

O3a results in brief

A three-fold increase in candidate detections p.13

The GEO-KAGRA Observing Run 3

KAGRA starts observing on 7th April, 2020 p.21

... and a look at the future of gravitational wave astronomy p.24

Front cover

Participants of the third Gravitational Wave Open Data Workshop from May 26 to 28, 2020, which was held remotely due to the COVID-19 pandemic.

Top inset: A still of a numerical relativity simulation consistent with GW190412.

Bottom inset: Sunset at GEO600 taken in May 2020.

Image credits

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

Cover: Main image from Syliva Biscoveanu / Gravitational Wave Open Data Workshop. Top inset: N. Fischer, H. Pfeiffer, A. Buonanno (Max Planck Institute for Gravitational Physics), Simulating eXtreme Spacetimes (SXS) Collaboration. Bottom inset: Nikhil Mukund.

p. 3 Comic strip by Nutsinee Kijbunchoo.
p. 6-12 Control room photo from Sharan Banagiri (p. 6); PPE donation photos from LIGO/Caltech/MIT/Joseph Giaime(p. 7); Instant camera photos by Georgia Mansell (p. 7); LIGO India lecture series poster from LIGO India / GW@Home (p. 8); Virtual defence photo by Ayelet Fishbach (p. 9); Virtual outreach photo by Jackie Bondell (p. 10); LSC Fellows in lockdown photo by Rick Savage (p.12).
p. 13-15 GW190412 numerical relativity simulation stills by N. Fischer, H. Pfeiffer, A. Buonanno (Max Planck Institute for Gravitational Physics), Simulating eXtreme Spacetimes (SXS) Collaboration. GW190814 graphics by LIGO/Caltech/MIT/R. Hurt (IPAC).
p. 16-17 Artist's impression of a magnetar from the European Space Agency https://www.esa.int/ESA_Multimedia/Images/2020/06/Illustration_of_a_magnetar. GEO600 sunset photo by Nikhil Mukund. KAGRA tunnel photo by Enrico Sacchetti.
p. 18-19 Photos from KAGRA / Masayuki Nakano.
p. 20-21 Photos from LIGO India / Vaibhav Savant.
p. 22-25 Artist's impression of NEMO by Carl Knox, OzGrav ARC Center of Excellence (p. 22); Cosmic explorer detectability of compact binaries by Evan Hall and Salvatore Vitale (p. 23); Strain sensitivity of current and future detectors by Evan Hall (p. 24); Artist's impression of the Einstein Telescope by Marco Kraan, Nikhef (p. 25).
p. 26-27 Timeline by Martin Hewitson (p. 26). Prototype positioning system photo by Dave Robertson, University of Glasgow (p. 27).
p. 31 Photo by Lucia Santamaria.
p. 32 Illustration by Jessica Steinlechner.
p. 35 Mask image from LIGO-Virgo Cafe Press. Photo by Nutsinee Kijbunchoo.

Back cover: Illustrations by Nutsinee Kijbunchoo.

Contents

Antimatter

Welcome to the 17th issue of the LIGO Magazine!

Welcome to the seventeenth issue of the LIGO Magazine! Throughout the world lives have been affected by the COVID-19 global pandemic, and we hear perspectives from around our own communities in "Stories from Lockdown" including working from home, online public engagement, and much more.

Observing Run 3 finished in March 2020 and the results continue to be analysed as I write. Several more exceptional observations have been released with more results to look forward to in "GW190412, GW190814, GW190521 + more in the pipeline". We also hear from Chihiro Kozakai and Nikhil Mukund about the joint observing run by KAGRA and GEO600 in April 2020, as well as news on how KAGRA is progressing from Masayuki Nakano.

In "Diversity in the LIGO and Virgo Collaborations" we hear from the chairs of the LIGO and Virgo Diversity groups, Ray Frey and Tania Regimbau, on the plans to address long-standing diversity issues within our collaborations.

Looking to the future, the next generation of gravitational wave detectors are being designed now, we hear the latest from three proposed facilities in "Improving the sensitivity of our future detectors". Turning to space, we hear the latest progress on the LISA mission in "Meanwhile in Space".

LIGO India recently took part in Vigyan Samagam, India's first of it's kind mega-science exhibition. We hear from Vaibhav Savant on the exhibition's success in bringing mega-science projects to over half a million attendees!

Finally, if you have ever wondered just how gravitational wave detectors stay stable despite the seismic motion of the Earth, find out on the backpage in "How it works: Seismic isolation at LIGO, Virgo, and KAGRA".

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

Hannah Middleton, for the Editors

News from the spokesperson

In February, I highlighted the success of Observing Run 3 (O3), the Collaboration's ambitious plans for publishing observational results, and the challenge of upgrading the LIGO detectors over the next few years. By the time that note appeared in print, we had already cancelled the in-person March LIGO-Virgo-KAGRA meeting as a result of concerns about COVID-19 and soon after that we ended O3 early. We have all faced adjustments to our personal and professional lives due to lockdowns, school closures, and restrictions on social interactions to reduce the spread of the disease. Our experience with remote collaboration enabled us to seamlessly continue working together although it took some time to establish safe working practices at the observatories and in our labs.

As we were grappling with the impact of the pandemic in May, the violent death of George Floyd at the hands of a police officer in the United States triggered demonstrations condemning systemic racism and discrimination. The response was not limited to one country, however. People around the world were spurred to action on these issues. At every level of our Collaboration, our members grappled with the issues, learned about the big and small ways our cultures and organizations can be systemically racist or biased, and came up with actions to improve our Collaboration. We strive to provide a welcoming, inclusive and safe environment for all our members. When we fail to do so, we must face that failure and do better the next time.

Our updated Bylaws were approved in June. Among the changes is the addition of a Committee on Diversity, Equity and Inclusion designed to strengthen our activities in these areas. The existing diversity group will continue to provide a venue where we can work together to improve the culture of our Collaboration. I hope that we will demonstrate leadership to the broader academic community.

Despite additional stress caused by the pandemic and the renewed urgency to address systemic racism and bias, we continue to produce important observational science papers based on O3 data and commissioning the Observing Run 4 (O4) instruments is ongoing. The new Operations Division is coordinating activities related to detector operations with the goal of bringing improved systems and processes online for O4. A number of requirements gathering, design and review activities are underway and there are many opportunities for LSC Groups to contribute to infrastructure and operations activities under this Division.

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. I encourage LSC members to participate in the Snowmass2021 particle physics community planning exercise. We can help develop the scientific case for gravitational-wave detectors as tools to push the Snowmass2021 Frontiers.

In these times of unusual stress, I urge you to be kind to each other and to yourself. I am always available to discuss your concerns or problems within the Collaboration.

Patrick Brady
LSC Spokesperson

Stories from Lockdown

Sharan Banagiri in the LIGO Hanford control room.

The COVID-19 pandemic has affected people's lives throughout the world. In this article, we hear perspectives and personal stories from around our community on the shutdown of Observing Run 3, remote working, meetings, and PhD defences, as well as outreach during lockdown.

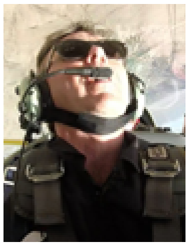
Turning Off O3

The LIGO Observatories were taken offline on March 27, 2020, bringing Observing Run 3 (O3) to a premature end more than a month earlier than planned. Deciding to end O3 in light of the tremendous success of the run was by no means simple.

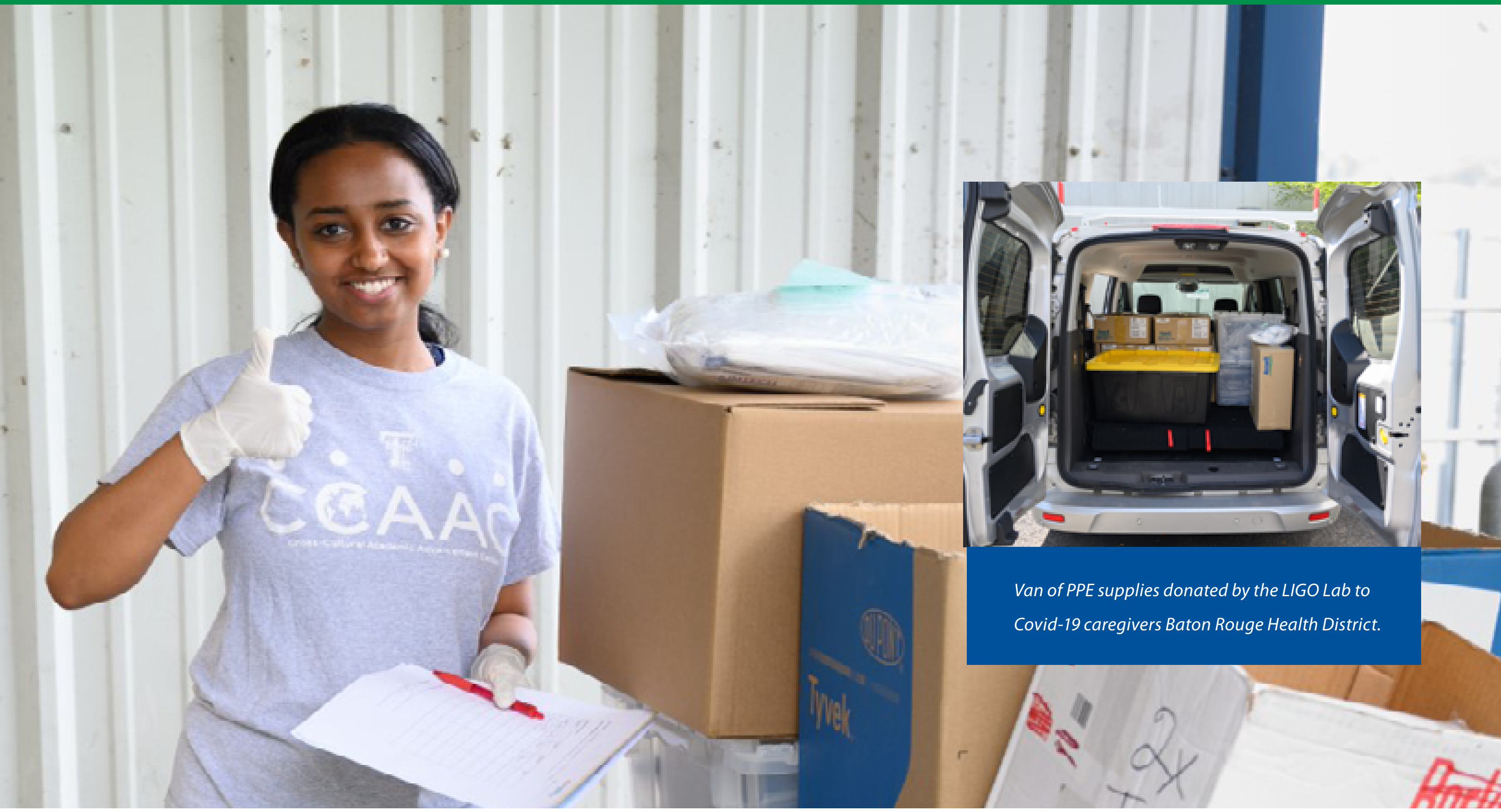
Getting to that decision involved many meetings in the weeks before the shutdown along with consultations with various stakeholders. It became clear in early March that the US was experiencing rapid growth in COVID-19 cases; Washington State was particularly hard hit, with Louisiana soon to follow (where LIGO Hanford and LIGO Livingston are located). Joe Giaime and Mike Landry (the Livingston and Hanford Observatory Heads) began rapidly developing plans to move to reduced observatory operations. The LIGO Laboratory Operations Management Team met frequently over a three week period to evaluate the plans and refine them to ensure that the transition was smooth and the observatories and detectors would be maintained in a safe state ('Phase 3') during an extended period.

LSC Spokesperson Patrick Brady was brought into the loop early on. In parallel, the campus based LIGO programs that support the Observatories were rapidly transi-

David Reitze



is the Executive Director of the LIGO Laboratory at Caltech in Pasadena and a Professor of Physics at the University of Florida. He enjoys hiking, continuing to improve his French language skills, and has been known on occasion to engage in extreme sports such as bungee jumping, parachuting, and combat dogfighting.



Van of PPE supplies donated by the LIGO Lab to Covid-19 caregivers Baton Rouge Health District.

PPE supplies donated by the LIGO Lab to COVID-19 caregivers being received by the Baton Rouge Health District depot.

tioning to remote work in accordance with Caltech and MIT guidelines. Consultations were held with the National Science Foundation to keep them apprised. Critically, a series of coordination meetings were held with European Gravitational Observatory (EGO) and Virgo leadership (Stavros Katsanevas and Jo van den Brand) the week before the shutdown to coordinate and synchronize LIGO-Virgo plans.

The final decision to enter Phase 3 was made on Sunday March 20. Ultimately, the decision came down to putting the safety of LIGO and EGO staff above all else. As I write this, we are beginning the transition out of Phase 3 to begin the upgrades planned for Observing Run 4 and implementing work procedures that provide a safe work environment for everyone.

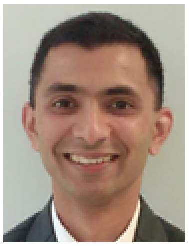
Georgia Mansell

is a postdoc at LIGO Hanford Observatory and MIT. In her spare time she can be found hiking, drawing, or playing Stardew Valley.

When the universities started closing I was visiting Caltech to take "2 weeks" worth of measurements of some new auxiliary optics for Observing Run 4. That was back near the start of March, and I'm still here! This has actually been quite fortuitous, since I have been allowed some lab access under lockdown. Working under lockdown for me has been part paper-writing and editing, part planning experiments I can do in the lab, and only a small part actually doing those experiments. It's been much harder for me to focus, and my work-life balance has tipped towards life. I've taken on some new hobbies, for example I recently bought a little instant camera and I've been trying to take some nice photos. One of the places I've been photographing is around the beautiful Caltech campus. While having some extra time to relax has been great, it has been increasingly hard to come to terms with the state of the world around me. I hope everyone is doing ok.

Georgia Mansell's photos taken with an instant camera around the Caltech campus.

Vaibhav Savant



coordinates the EPO activities of LIGO-India at the Inter-University Centre for Astronomy & Astrophysics, Pune. During his free time he enjoys training dogs and meditation.

LIGO India during the COVID-19 lockdown: GW@home

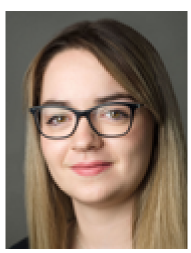
GW@Home with LIGO-India is an online lecture series on gravitational waves. It was conducted by LIGO-India as part of an initiative to engage with its followers during the coronavirus lockdown. From 1st April to 20th May 2020, twenty one online talks were streamed on YouTube Live. Experts from various relevant backgrounds held the online audience captive with their hour long talks. A live Q&A session followed the talk where the speaker answered questions from the audience.

The objective of the programme was to educate undergraduate and postgraduate students about the diverse sub-domains in gravitational wave astronomy and corresponding career opportunities. Bearing in mind that an important component of the talk was also to create awareness amongst the masses about the LIGO-India project and its benefits to science and society at large, the speakers ensured that there was something for the general public to take from the talks as well.

GW@Home with LIGO-India also marked the launching of the official LIGO-India YouTube channel. With 4.75K subscribers and counting, the series surely is creating waves!

GW@Home with LIGO-India: www.youtube.com/c/LIGOIndia

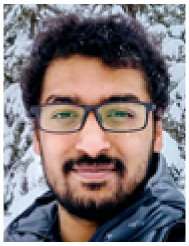
Sylvia Biscoveanu



is a third year graduate student at MIT working on compact binary parameter estimation and stochastic backgrounds. A Philadelphia native, she is also an avid violinist and enjoys hiking and cuddling her cat.

The third Gravitational Wave Open Data Workshop was originally planned to take place in Silver Spring, Maryland. As the prospect of travelling became more uncertain due to the spread of COVID-19, it was decided to move the conference online. The workshop serves as an introduction to LIGO data analysis for a wide range of audiences. It features both lectures and hands-on coding tutorials. Under the direction of principal conference organizer Jonah Kanner, a diverse group of mentors spanning different areas of expertise and different time zones assembled to edit tutorials and plan for how to best enable the valuable in-person interactions in the hands-on sessions virtually. The conference registration quickly filled up since many people who wouldn't have been able to attend in-person could now participate, and the workshop kicked off with lecture sessions in the morning and small group tutorials—with mentors working closely with participants—in the afternoon. Even though preparing my first invited conference talk and optimizing the tutorial sessions for a virtual meeting required major adjustments and planning, the positive feedback from the participants and their requests for future Open Data Workshops to have an online component made it worth it in the end.

Sharan Banagiri



is originally from India and is a PhD candidate at the University of Minnesota. He likes his PS4, playing board games, reading fiction and biking around Minneapolis in the summer.

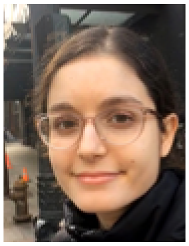
"May you live in interesting times!"

When I first came across this expression last year, I thought I probably wouldn't mind some interesting times. Little did I know that they were around the corner.

Like almost everyone else on the planet, the pandemic has upended life-as-usual for me. Minnesota has so far been spared the worst of it and lockdown has mostly involved boredom, minimal human contact, virtual board games, being careful at supermarkets and a love-hate relation with Zoom. The hardest part has been having to endure it away from my family, stuck literally on the opposite side of the world. With few international flights and quarantines on arrival, traveling back in cases of emergency isn't really an option. It is hard for me and I know for many international students and postdocs to not feel isolated from family. If you are in a similar position I hope you can see that you are not alone.

Of course no one is alone since the whole planet is in on this bizarre experience. Once the pandemic became global my mind almost immediately connected it to the other shared catastrophe that we know is here, climate change. If there is a sliver of silver lining to this experience, I only hope that this will awaken us to the perils of climate change and make us realize that we really have to act.

Maya Fishbach



recently graduated with a PhD in astronomy from the University of Chicago, and will soon start as a NHFP Einstein Fellow at Northwestern. She enjoys baking pretzels, drinking boba, and playing with her dog or her hamster.

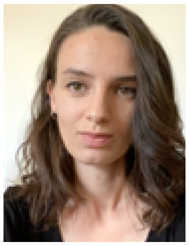
When I first began planning for my PhD defense, my biggest worry, considering my committee members' busy travel schedule, was finding a time that we were all available. This concern soon became obsolete. As the pandemic cancelled summer plans and everyone settled into lockdown, scheduling a virtual PhD defense became the easiest thing in the world. I defended my PhD from the basement of my parents' house, which currently serves as my office.

In the monotony of the early lockdown days, my defense was a rare festive event, which made it especially exciting. Joining me in my Zoom room was my family (who was sitting upstairs), my PhD committee, including my advisor in his house across the street, members of my department, and a few friends who live in different cities and would never have been able to attend a normal, in-person defense. Afterwards, we found creative ways to celebrate. Instead of sharing a bottle of champagne, we raised glasses of bubble tea over Zoom, a nod to the group meetings we used to hold at the campus boba shop. My eight-year-old brother played "Pomp and Circumstance" on the piano as my sister presented me with a chocolate cake shaped like the merger of two black holes. It was a memorable day to become a doctor.

Dobby, Maya's dog, watches with interest as Maya defends her PhD through a laptop screen.

LIGO in Lockdown

Leïla Haegel



is a postdoctoral researcher analysing gravitational waves data with the Virgo experiment. She finds black holes fascinating, although she is not sure that they are more complicated than trying to mix a physicist and a family life.

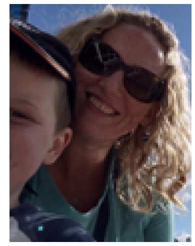
Academia had already made me experience the strange dynamics of a 2-body system when a postdoc made my couple transition to the long-distance regime. But physics was right: a 3-body system is incredibly more complex, and the arrival of our baby last Summer made us realise so. As I work in France and my partner in Switzerland, a long series of perturbations occurred during the weekly train ride to spend half of the week together, and a chaotic behaviour definitely emerged in our schedules. The announcement of the French lockdown while I was in Switzerland therefore felt like finding a stable configuration despite the tumultuous state of the world. The energy that was not lost in friction against the incredible amount of trams, trains, and subways that we had to ride could be reinvested in increasing the binding of the little system of our family — and protecting it from viruses. If the first period of working from home with a baby was a clear demonstration of how much energy and time consumption a little human being can absorb, finding a kindergarden open during the Swiss lockdown enabled me to orbit again around my laptop and re-find productivity. But the most important of all is our loved ones being unaffected by the pandemic and our little progenitor being so happy to constantly be with his two parents.

Deep Chatterjee

is from Kolkata, India and received an integrated BS-MS in physics from the Indian Institute of Science Education and Research (ISER), Kolkata in 2015. Deep has just received a Ph.D in physics from the University of Wisconsin-Milwaukee and will be joining the University of Illinois Urbana Champaign as a NCSA CAPS fellow in Fall 2020. Besides work, Deep likes to travel, listen to music, play guitar and sing.

My PhD defense was on April 16, 2020. In the U.S., the impact of COVID-19 took off around the second week of March. In the days that followed, conferences were cancelled (including the LIGO-Virgo-KAGRA meeting), travel was restricted, university employees were asked to work from home. It became clear that the defense would have to be a remote one. The remote part of the defense did not bother me much having worked in an international collaboration. I had to manage a chalkboard, which was easily resolved via screen sharing a scratchpad on my tablet. It was, in a sense, easier to get set up. I didn't have to go anywhere, or fiddle with the projector, find the cable that worked, or scrounge for the laser pointer. I joined Zoom using both my laptop and tablet. The complete thing lasted about two and half hours. The questions were mostly regarding the content of my thesis and on problems I intend to tackle in the future. It was interactive and engaging, quite unlike the popular cliche of a grill. I was put in a Zoom waiting room, a feature I had not appreciated earlier, and was eventually called in and told that I passed. The feeling after was like getting done with a difficult exam successfully. I finally submitted during the first week of May (DCC: P2000128). I was the first instance of a successful remote defense in the University of Wisconsin-Milwaukee physics department.

Jackie Bondell

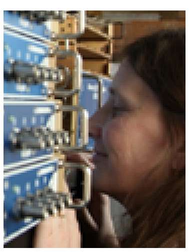


is the Education and Outreach Coordinator for OzGrav and based at Swinburne University of Technology. Her favourite aspect of her work is developing workshops and lessons to help teachers introduce gravitational wave concepts in their science lessons. When not working, she can be found trying to keep up with her kids or rowing along the Yarra River.

One of the most rewarding aspects of doing outreach is meeting with people face-to-face to engage audiences with the awe of gravitational wave discoveries. At OzGrav, we have built a robust Education and Outreach program based on visiting schools, hosting professional development for teachers, and meeting audiences at large science festivals. When our lockdown started, the expected melancholy settled in as every event on our calendar was cancelled or postponed. After this initial flurry of reconfiguring our schedules passed, we were faced with the inevitable 'now what?' We dusted off our old notebooks and looked back at those ideas that we wanted to initiate, but hadn't yet. Slowly our mindsets shifted from viewing our situation as one of challenges to one of opportunities. We went to work creating more virtual materials for our audiences: videos to guide the public through our free apps, livestream talks to give our early career researchers opportunities to present their work, an updated outreach website, and online instructional modules for teachers. Most notably, we developed free-of-charge, remotely-delivered versions of our in-person school incursions. These virtual incursions had been on the 'to-do' list for a while with the intention of scaling our resources across geographic and socioeconomic barriers. In the last few weeks of the Australian school term, we engaged with well over 100 teachers and students not only across rural areas of Australia but in Europe and North America as well! While the lockdown may have put up physical barriers in the outreach space, we have embraced the opportunity to bring gravitational wave science to new and diverse audiences.

At her home, Jackie Bondell prepares to lead a school session for Year 7 students.

Zsuzsa and Szabi Marka



of Columbia University are decades-long members of LIGO, pioneering multimessenger astrophysics, mission-critical instrumentation, machine learning, and more. They are raising four children in New York City.

10 things...

1. Acted right away: donated PPE from the lab to the Columbia Presbyterian Hospital.
2. Sadly, we had to say goodbye to the grandmother who has been visiting us. It was not safe for her to stay as schools closed rather late in the City.
3. Built a new home environment to support remote learning for four children, and remote work for two adults.
4. Emailed and called family, friends, and colleagues to support them and learn about how they are doing.
5. Examined how we can help to make the Earth a better place for all. We invest a lot already but we can do more.
6. Energized many around us and made new friends and collaborators who wanted to help in the COVID-19 effort, even our children helped in the research, development, and publications. We expanded our core and built a new international collaboration.
7. Spent tremendous time on zoom, especially with students!
8. Helped the university in restructuring its instruction and planning for the next school year.
9. Read and wrote many-many scientific papers on a variety of topics: from machine learning through microlensing, Shapiro delay, neutrino emission, hierarchical triples, to COVID-19.
10. Took some time to rest in the forest as Nature made us to.

Aaron Jones

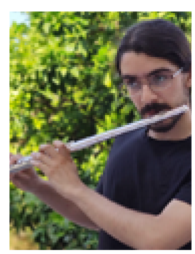
is a PhD graduand at the University of Birmingham, where he started his PhD in September 2016. When he is not researching the effect of higher-order optical modes he can be found tinkering with the "Gravity Synth", improving "Chirp" or on Twitter @phyaaron (aaronwjones.com).

Over the last few years, I had developed a few expectations about my viva (PhD defence). In the British system, one is typically in a room with two examiners and a chair until they deem you worthy of a PhD. In my research group, viva's typically ranged between 2 and 5 hours. There are very few exceptions to this format and the University of Birmingham is very clear that the viva must not be held via video link without special approval from the University Senate. So I have been pretty certain to expect that during my PhD.

I hadn't anticipated a global pandemic changing this format. Fortunately, the Senate stepped in and offered all students a "zoomva" (viva over Zoom). This was a slightly surreal, but very fun experience. After the first few minutes and the initial audiovisual checks, the cadence of the viva increased and I almost forgot it was by video link. Some aspects were odd, such as discussing figures, but overall there were no problems and it was really fun.

The biggest difference was the day of the viva. I had planned to start by sharing "the last coffee" with friends and finish the day by visiting one of Birmingham's excellent public houses. Instead, all of this was conducted via 13 hours of nearly continuous Zoom call. I'm actually really glad, as I got to spend time with some previous colleagues who had moved away.

Rodrigo Tenorio



is a PhD student at the University of the Balearic Islands (Spain) interested in data analysis and continuous gravitational waves. Rodrigo enjoys programming and playing music in his spare time.

The LSC Fellows program allows LSC scientists from all around the world to engage in activities at one of the LIGO sites, directly contributing to the improvement and enhancement of scientific products delivered by the collaboration. This is such a great opportunity to get in touch with one of the most fascinating experiments running nowadays; however, this time turned out to be different...

LIGO in Lockdown by the LIGO Community

Dripta Bhattacharjee

is a graduate student at Missouri University of Science and Technology, working with Dr. Marco Cavaglia mostly with the calibration group of LIGO. Dripta is a trained Indian classical dancer and in likes reading books in her spare time.

Global response to COVID-19 was quite diverse among different countries: some decided to impose a lock down for everyone, while others preferred to procrastinate taking action. Nevertheless, strategies were changed week by week, so each week looked different from the last. This spicy international situation had a direct impact on our own decisions regarding what to do next, "fly, you fools!" and "freeze!" being the two most popular choices.

Some of us decided to take a chance and fly back home (whatever "home" means during a global pandemic). This proved to be quite tricky, since some countries were pondering over closing borders to foreigners no-matter-what. Of course, you could enter your own country if you got to its borders, the question was whether you could reach them or not, given that the number of international flights was decreasing. After a couple of stressful phone calls and e-mail involving advisors, administrators, family, and friends, things were good to go and a first group of fellows left the LSC Fellows' apartments in an unprecedented fashion.

Another group of fellows decided to stay in place. Multiple arguments came up through a similar chain of e-mails and phone calls, even though nothing was really clear during those times: Questions like "How much is this going to escalate?" "How long is this going to take?" or "When will be international flights available again?" popped up multiple times, and the answer was usually along the lines of "well, give it a month or two to settle down a bit", which seemed a reasonable time for the world to understand this new world order to which we were all (forcibly) dragged in.

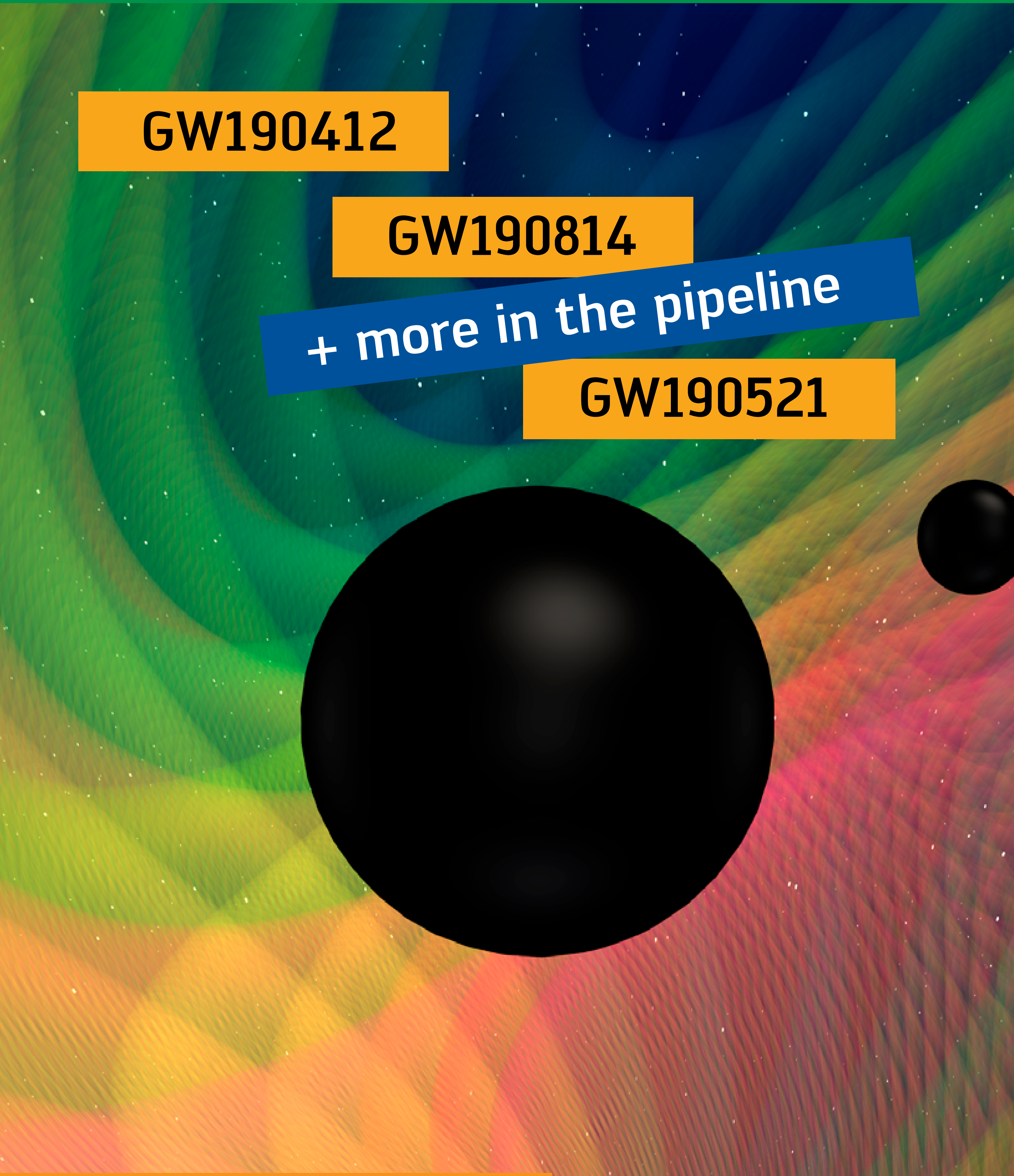
In the meantime, the LSC made a decision, asking people to telecommute whenever possible. This led to an interesting set of changes at the Fellows' place, which became an improvised office in a matter of days: screens, cables, keyboards… Everything had to be moved around following social distancing rules, meaning someone would carry stuff to our door and we would wait 5 seconds before picking it up, allowing the person to move away. All of a sudden, every out-of-home activity, doing groceries included, was closer to a protocol than to a chore (assuming those are different things).

This whole situation also led to one of the most loved/hated things related to telecommuting: Teleconferences. Let it be WhatsApp, TeamSpeak or Zoom, they all became part of our day-to-day working routine. Zoom backgrounds deserve a special mention, since they represented a conscious choice made by individuals to present themselves to their peers: The same way a person chooses how to dress, a person makes a choice through Zoom backgrounds.

As of now, the number of LSC fellows has drastically decreased. Those buildings, formerly dwelled in by young soon-to-be scientists eager to learn the good way to Science, became empty, stripped of generations of untold stories. There is no clear end to this phenomenon, let alone a clear time scale about when things will go back to normal. While we wait for the world to return to our previous notion of 'normalcy', fellows have adapted to the new notion of normalcy swiftly. From helping each other out with groceries, sharing banana bread and coffee custard with each other, getting pizza's delivered to the doorstep by our local fellow's in-charge, masks delivered by colleagues, fellows found a way to deal with the pandemic. The only thing that always kept us edgy more than COVID-19 was the sudden disappearance of toilet paper and kitchen towel from the grocery shops.

LSC Fellows Rodrigo Tenorio and Dripta Bhattacharjee during lockdown at Richland, Washington State.

O3: Three-fold increase in candidate events

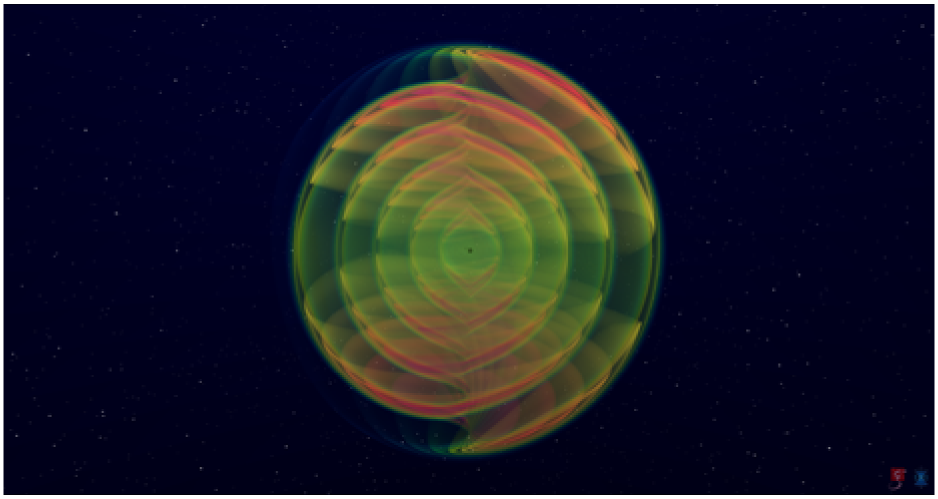


GW190412: A binary black hole merger with asymmetric masses.

The image is a still from a numerical relativity simulation of the merger.

Since our last issue of the LIGO Magazine, three further exceptional events have been announced from LIGO and Virgo's third observation run (O3). O3 ran from April 2019 until its early suspension in March 2020, about a month prior to the planned date due to COVID-19. The run had a month long break during October 2019 for detector work and is divided into O3a and O3b for before and after the break.

So far, four exceptional events have been announced from O3. We looked at GW190425 in issue 16 of the LIGO Magazine. Here we introduce the detections of GW190412, GW190814, and GW190521. There are many more results to look forward to: O3 saw a three-fold increase in candidate events! These will be presented in an upcoming catalog of observations.



A still of a numerical relativity simulation consistent with GW190412.

GW190412: the first black hole merger with unequal mass

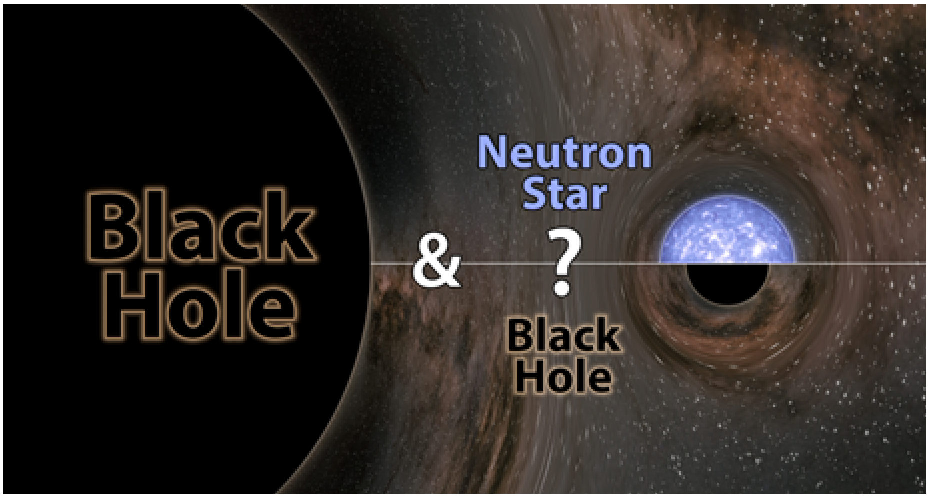
GW190412 was observed on the 12th April 2019 by both of the Advanced LIGO detectors (in Hanford, Washington and Livingston, Louisiana) and the Advanced Virgo detector (in Cascina, Italy) operating as a three detector network.

The gravitational waves were produced by the mergers of two black holes. One of the black holes was about 30 times the mass of the Sun and the other was about 8 times the mass of the Sun. GW190412 is therefore the first binary black hole merger in which the two black holes are definitely unequal in mass - the black hole with the larger mass is more than 3 times the mass of the smaller mass black hole it merged with. (Another even more asymmetric merger is GW190814, described below on the next page.)

Besides the masses of the black holes, we are also interested to learn about their spin. The more massive black hole spin is measured to be about 40% of the maximum spin allowed by general relativity.

The orbital frequency of a binary corresponds to how many times the two objects orbit each other in a second. The frequency of gravitational waves from binary mergers is twice the orbital frequency of the binary. Using the analogy of sound - the main gravitational wave emission at twice the orbital frequency is similar to the fundamental frequency heard when plucking a guitar string. However it is also possible to have emission at harmonics of the fundamental frequency. In music these higher frequency harmonics are also called overtones. Asymmetric systems like GW190412 are predicted to emit gravitational waves with stronger higher harmonics and indeed this observation provides strong support for their emission.

For more information on this discovery visit www.ligo.org/science/Publication-GW190412/index.php



GW190814: A signal from the merger of a black hole with an object which could either be a neutron star or a black hole.

GW190814: one black hole and one unidentified object

GW190814 was observed on the 14th August 2019. It was also observed by both the LIGO and the Virgo detectors. It is an especially intriguing source of gravitational waves produced by the inspiral and merger of two compact objects: one is a black hole but the other object's identity is undetermined.

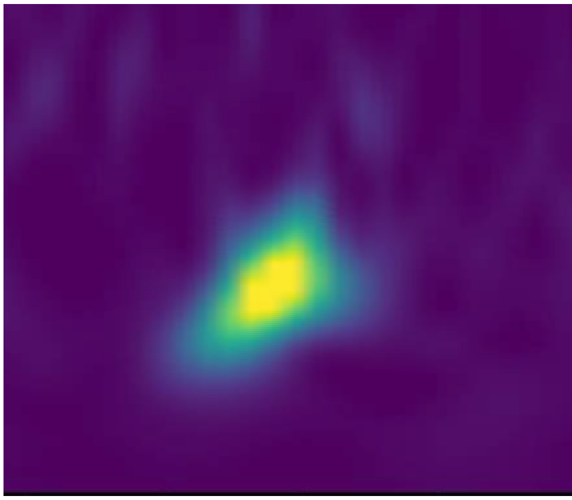
The heavier object in GW190814 has a mass approximately 23 times the mass of our sun, consistent with other black holes observed by LIGO and Virgo so far. The mass of the lighter companion is between 2.5 and 3 times the mass of our sun.

Similar to GW190412, these two compact objects are unequal in mass. In this case the heavier object is about 9 times more massive than its companion, making it the most asymmetric system observed with gravitational waves to date. The black hole's spin was also measured and this time its spin is less than 7% of the maximum spin allowed by general relativity.

What about the mystery companion? It could either be the lightest black hole or the heaviest neutron star discovered in a system of compact objects. But we can't be sure which. Its mass lies in the range called the "lower mass gap" which ranges from around 2.5 to 5 times the mass of our sun. There are few observations of compact objects in this mass range suggesting a gap between the heaviest mass of a neutron star and the lightest mass of a black hole.

GW190814 poses some interesting questions on the masses of compact objects, their formation, and the properties of neutron star matter. Future observations of asymmetric mergers like this one will help us learn more about the mysteries of GW190814.

For more information on this discovery visitit www.ligo.org/science/Publication-GW190814/index.php



GW190521: The gravitational wave signal as seen in the instrument at the LIGO Hanford observatory.

GW190521: Hot off the press!

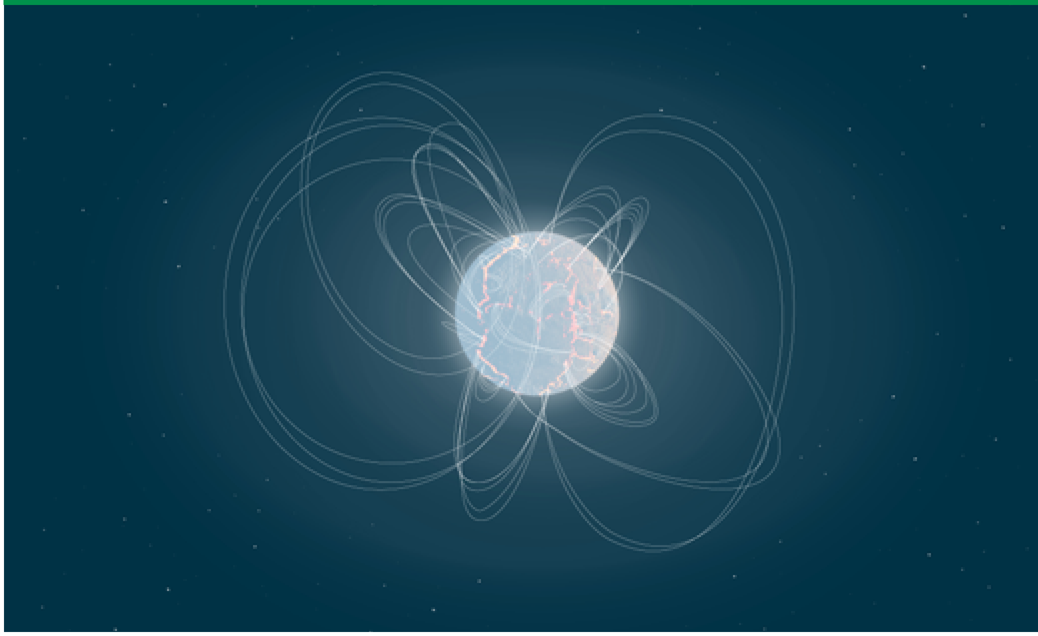
The detection of GW190521 by LIGO and Virgo was very recently announced. Observed on the 21st May 2019, GW190521 was produced by the merger of two black holes. However, this is no ordinary black hole merger - the two black holes are more massive than any of the merging black holes observed by LIGO and Virgo so far!

One black hole was around 85 times the mass of our sun and the other was around 66 times the mass of our sun. After merging together, the resulting black hole weighed in at around 142 times the mass of our sun. This is the first clear detection of an "intermediate-mass" black hole (between steller-mass and supermassive black holes).

For more information on this discovery visitit www.ligo.org/science/Publication-GW190521/index.php

Stay tuned for more results and analysis from Observing Run 3!

The GEO-KAGRA Observing Run 3



Magnetars are neutron stars whose magnetic files are particularly strong. Artist's impression from ESA.

In April 2020, the KAGRA and GEO600 gravitational wave observatories made a joint observation run - O3GK (Observing Run 3 GEO-KAGRA). O3GK took place after the LIGO and Virgo observatories suspended their third observing run operation early on 27th March 2020 due to the COVID-19 pandemic.

Chihiro Kozakai and Nikhil Mukund tell us more from KAGRA and GEO600.

Chihiro Kozakai

is a Japan Society for the Promotion of Science fellow in the National Astronomical Observatory of Japan, working on detector characterization of KAGRA. On holiday, she loves playing viola in orchestra, traveling, and cooking.

O3GK at KAGRA

KAGRA is the gravitational wave (GW) observatory in Kamioka, Japan. We are building the first underground GW observatory with cryogenic mirrors. For GW observations, having multiple detectors is important as it allows us to get accurate sky localizations of GW sources (which is useful for multi-messenger astronomy), to measure the polarizations of the GWs, and to reduce the downtime of the detector network. Therefore, we rushed to join the observation network as soon as possible.

KAGRA started observing on the 7th April, 2020. As in most regions of the world, we had to avoid travel and the "3Cs" (Confined spaces, Crowded places, Close contact) to limit coronavirus infections. As KAGRA does not have dedicated interferometer operators, the original plan was for the detector to be operated in turns by many members of the KAGRA collaboration. However, since we could not accept any off-site people at that time, we decided to schedule the control-room shifts with people who were already on site and limited the number of people in the office to a minimum. Unfortunately, the Advanced LIGO and Advanced Virgo detectors had suspended their O3 run at that time. However, GEO600 was still operating and thus KAGRA could have a joint observation run with them, O3GK. We continued the joint observation for two weeks, until April 21st.

The binary neutron star range (BNS range) is used as a performance indicator for GW observatories. It is the average distance to which we can detect a binary neutron star merger. During O3GK, KAGRA typically had a BNS range of 600 kilo-parsecs (kpc) and a duty cycle (the percentage of time spent collecting astrophysical data) of 53.2%. Severe weather conditions were to blame for some part of the long downtime. Seismic noise caused by sea waves can reach KAGRA's underground tunnels. In stormy weather, this seismic noise disturbs the stabilization of KAGRA's mirrors, and it is difficult to keep the interferometer in observation mode. This problem is a task for the future.

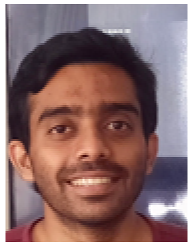
During O3GK, several gamma ray bursts (GRBs) were observed including a short GRB by Fermi Gamma-ray Burst Monitor and Fermi Large Area Telescope, called GRB200415A. It is located within the Sculptor Galaxy (also called NGC253), which is at a distance of 3.5 mega-parsecs (Mpc) from Earth. This event might be a giant flare of a soft gamma repeater (SGR), which are thought to be related to magnetars. The giant flares of SGRs are rare events as only six of them have been observed since 1979. Originally, KAGRA was under maintenance at that time. However, it turned out that the maintenance was in the final check phase and that the interferometer configuration was set as nominal soon after that. Therefore, we judged this data to be suitable for scientific analysis. Follow-up analysis of the data around these GRB events, including more careful data quality checks are ongoing now, together with the GEO600, LIGO, Virgo teams.

In O3GK, KAGRA got its first experience of a joint observation run and this interesting rare astronomical event alert. We also discovered many open issues which need to be addressed before the next observation run. We are looking forward to having joint observations with LIGO and Virgo with the upgraded KAGRA detectors in the near future. Let's never stop listening for gravitational waves.

O3GK at GEO600

For folks working at GEO600, the only kilometer-scale Michelson interferometer with folded arms, participating in a joint science run with KAGRA was somewhat unexpected yet an exciting opportunity. Located in Ruthe, Hannover, the observatory has traditionally operated in an AstroWatch mode, collecting gravitational wave strain data alongside the other larger detectors. Amid the Covid-19 crisis, we decided to keep the instrument running by taking shifts while maintaining appropriate social-distancing. Since most of us prefer biking, commuting to the GEO600 site was hardly an issue. Thanks to our operator's timely inspection and maintenance efforts, and the automatic lock acquisition system in place, we managed to achieve a duty cycle of 80% and a BNS range of just above 1 Mpc.

Nikhil Mukund



is a junior scientist working at AEI Hannover, since 2019. Apart from doing interferometer commissioning work at GEO600, he likes to train AI systems to generate tones similar to Ragas, the essential melodic structures of the Indian classical music tradition.

Besides seismic noise, there were a couple of 'unusual suspects' that resulted in the site experiencing some downtime. Since the vacuum fix operation last year, where the entire north arm got vented with pure nitrogen (see LIGO Magazine Issue 16, p. 20), there were hardly any issues keeping air out of the 600 m long arms. Three days into the run, one of our scroll vacuum pumps went 'kaput' and was urgently replaced with a spare. Another issue arose from the controls and data acquisition system that caused the front-end computers to crash intermittently during the run. These events temporarily hampered the detector's ability to remain in a low noise mode necessary for carrying out the desired astrophysical observations. After a series of investigations, we finally figured out their correlation with glitches in the power supply and fixed it swiftly by switching to a more stable power source.

The GRB event on the 15th of April spurred a lot of enthusiasm, and luckily enough, GEO600 was in 'science mode' at that time. The follow-up discussions regarding the origin of this astrophysical event and the noise hunting efforts around the trigger time provided the much-needed action to overcome the lockdown boredom. In the end, it turned out to be a magnetar flare from the Sculptor galaxy. In the weeks after O3GK, we devoted time to carry out several calibration and electronic transfer function measurements. They confirmed the validity of the gravitational wave strain signal reconstructed from the detector data (from the main photodiode signal fluctuations and the longitudinal feedback signals). We are hoping to provide an improved version of the strain signal with fewer systematic errors soon.

Overall it was a rewarding experience to participate in this science run with KAGRA. It also stresses the advantage of having a network of detectors which are capable of making such joint observations. The observatory is now getting back to its usual "instrument science mode" with experiments related to thermal compensation, squeezing beyond 6dB, and neural-network powered control systems proceeding in full swing.

Sunset at GEO600. Taken in early May next to the GEO600 main entrance gate after a long day of calibration measurements.

KAGRA 3km arm cavity in the underground tunnel.

Commissioning KAGRA - tough fun

Celebrating the first lock of the power recycling Fabry-Pérot Michelson interferometer (PRFPMI) in August 2019.

Masayuki Nakano

is a Postdoc at the University of Toyama. He has worked on KAGRA since 2014, when nothing was in the tunnel except for stones, soil, and water.

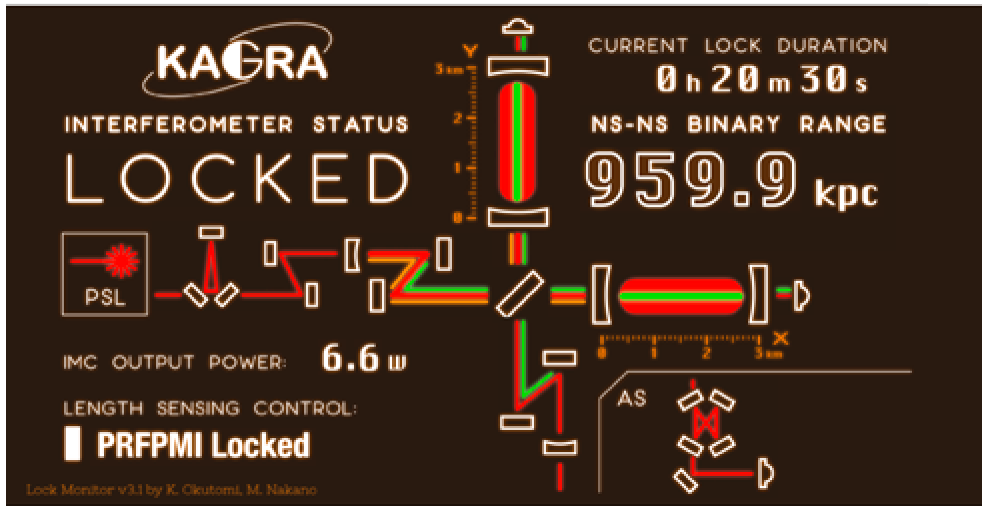
Similar to the commissioning of other gravitational wave observatories, KAGRA commissioning work in preparation for Observing Run 3 (O3) was tough, but at the same time, so fun. Some of us worked like an extraterrestrial worker: we did not care about sunrise and sunset, and sometimes, there were 27 hours or more in one day. Even with such a crazy working schedule, we were enjoying setting up an exciting interferometer experiment a lot.

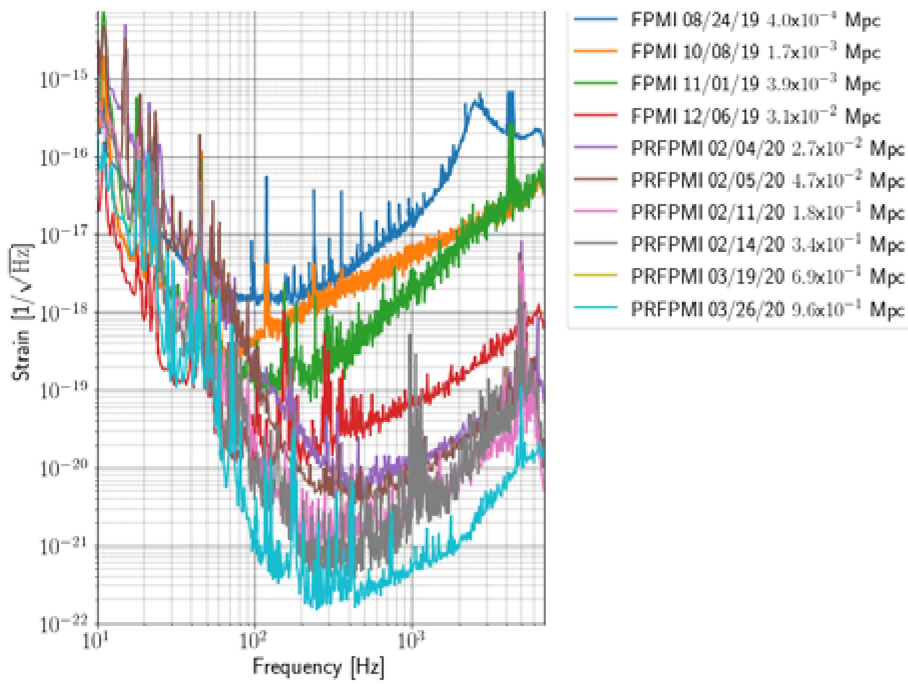
KAGRA's interferometer configuration is similar to the other gravitational wave detectors. The basic idea of the configuration is the Michelson interferometer, which can detect tiny arm length fluctuations caused by gravitational waves. Three of KAGRA's components are the 3-km Fabry-Pérot arm cavities to enhance the response to gravitational wave interaction; a power recycling cavity to increase the laser power circulating in the interferometer; and a signal recycling cavity to shape up the quantum noise. Together, the first two parts (Fabry-Pérot arm cavities and power recycling cavities) are called a 'power recycling Fabry-Pérot Michelson interferometer' (PRFPMI). In this period, we have succeeded in operating the PRFPMI. The PRFPMI can be automatically 'locked', which means all of the Michelson interferometer, the arm cavities, and the power recycling cavity were controlled on the operation point (the state in which observations can be made) at the same time.

Our interferometer was locked in August 2019 for the first time. At this moment, the power recycling cavity had not been introduced yet, and our binary-neutron-star (BNS) range was about 100 parsecs. (The BNS range is a standard measure of how sensitive a gravitational wave detector is - it tells us the detector's range for observing binary neutron star merger signals: a larger BNS range means the instrument can detect signals from further away in space). Our goal of the BNS range for this observation was 1 Mpc (a million parsecs). So, we needed a 10,000-fold improvement in sensitivity. To achieve this task within half a year seemed almost impossible, but we didn't give up. We modified the laser stabilization system, improved the suspension control loops, succeeded in locking the power recycling cavity, covered the vacuum chambers with soundproof materials, introduced the DC readout technique, among other things. Many experts from LIGO and Virgo kindly came to KAGRA and helped us a lot. Some of these noise hunting efforts improved the sensitivity by as much as an order of magnitude, and finally, we recorded the best BNS range of 960 kpc (960,000 parsecs) at the end of March 2020.

From April 7th, our first joint observation with GEO600, O3GK (see p. 16), started. Unfortunately, the sensitivity during O3GK was not as good as our best capabilities. However, we had one exciting event, GRB200415A, with our interferometer in observation mode. Actually, we could not have operated the interferometer without luck for this event. At the time, KAGRA's interferometer had not been operated for a day due to an accident that happened one day before the event. The maintenance work took a whole day, and we fixed the problem just minutes before GRB200415A.

The next steps are to begin modifications towards Observing Run 4. The first project is the commissioning of a dual recycling Fabry-Pérot Michelson interferometer (DRFPMI): adding the signal recycling cavity into the PRFPMI. We will lock the DRFPMI, and then open the vacuum to modify and install the hardware such as suspensions, baffles, new modulation system, and so on. After installation work, we will cool the mirror down to cryogenic temperature to reduce the thermal noise. We still have many difficult but also exciting tasks before listening to gravitational waves.





Top: *Screenshot from the control room at the time of KAGRA's best sensitivity so far (March 2020) showing the layout of KAGRA and the binary neutron star (NS-NS binary range) sensitivity of 959.9 kpc.*

Bottom: *The sensitivity history of KAGRA from the first PRFPMI lock in August 2019 (in dark blue) to the best sensitivity so far on 26th March 2020 (in light blue). The plot shows the sensitivity of the detector on the y axis and how it depends on frequency on the x axis. The lower the line, the better the sensitivity.*

Vigyan Samagam: LIGO India at mega-science exhibition

Left: *An entire family admires the LIGO-in-your-hands advanced interferometer demonstration and the Stretch and Squash app.*

Right: *A young GW enthusiast browsing through our touchscreen info-kiosk's 'Did you know?' section.*

Vaibhav Savant

is coordinating the EPO activities of LIGO-India from the Inter-University Centre for Astronomy & Astrophysics, Pune. During his PhD studies at the Cork Institute of Technology he worked on developing automated data acquisition and processing pipelines for robotic telescopes. When not working, he enjoys recreational flying, training dogs and meditation.

LIGO-India was a part of India's first-of-its-kind mega science exhibition - Vigyan Samagam from May 2019 to March 2020. Vigyan Samagam, which means 'Science Confluence' in Hindi, was co-organised by the Department of Atomic Energy (DAE), the Department of Science and Technology (DST) and the National Council of Science Museums (NCSM). The travelling exhibition visited four major cities in India - Mumbai, Bengaluru, Kolkata and Delhi, covering all four corners of the country in one year. While being stationed in each city for 2 months, the exhibition was open to anyone and everyone.

The objective of this unique exhibition was to bring mega-science projects closer to the society and to provide a common platform for students, academicians and industries to interact. And what a success it has been. With a cumulative footfall of more than half a million at three venues, Vigyan Samagam had to be concluded a few days early in Delhi because of the COVID-19 lockdown.

A total of seven mega-science projects, which have an Indian participation or partnership, initially took part in this endeavour - European Organization for Nuclear Research (CERN), Facility for Antiproton and Ion Research (FAIR), Indian Neutrino Observatory (INO), International Thermonuclear Experimental

Reactor (ITER), Laser Interferometer Gravitational-wave Observatory (LIGO), Square Kilometer Array (SKA) and the Thirty Metre Telescope (TMT). They were later joined by the all-Indian Major Atmospheric Cherenkov Experiment (MACE) telescope project.

Each project booth had ten posters providing visitors information such as the objective and significance along with working principles, the challenges involved and India's role in it. Working demonstrations and static models at the booth further helped in explaining these in a simplified manner. A display playing short documentaries and a touchscreen info-kiosk kept people of all ages engaged. The LIGO-India EPO team began painstaking preparations months before the exhibition - compiling poster content, designing the touch interface, putting together the exhibits and demos etc. Several reviews ensured public friendliness of the English text of the bilingual posters and their translation to Hindi. Locally sourced volunteers, mostly undergraduate/postgraduate students of science or engineering, were trained and assigned to help visitors navigate the booth and answer any queries. Like all projects LIGO-India also took up an "outreach week" where it organised a set of fun activities that included live demonstrations, games and talks for a mixed audience which further aided in stimulating popular interest in the project.

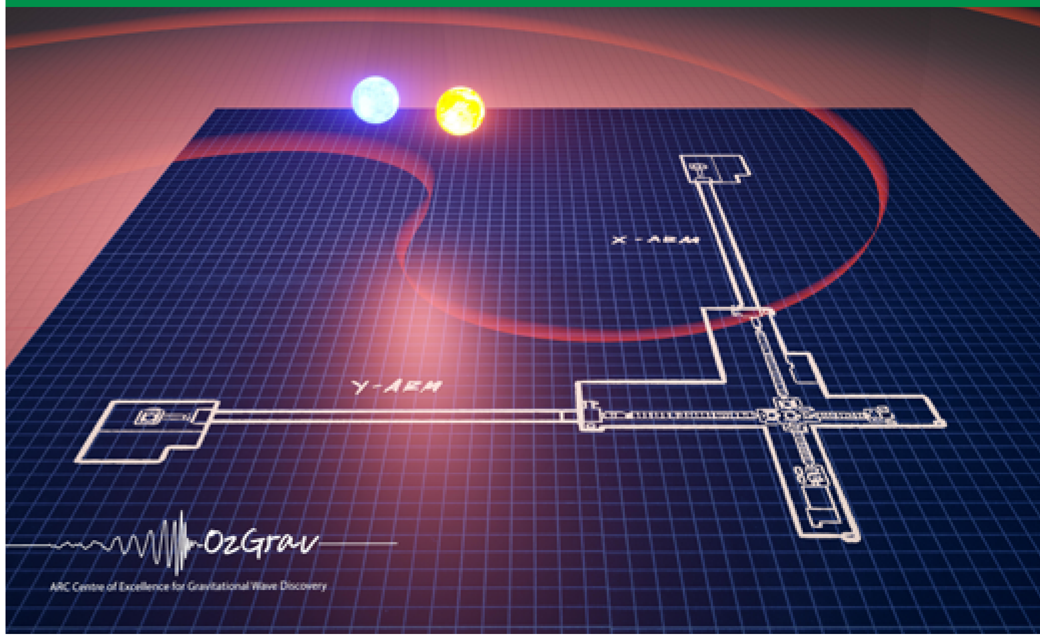
Prof. Patrick Brady and Dr. David Reitze gave inaugural talks for Vigyan Samagam while the exhibition also provided visitors the opportunity to interact with people of prominence like Prof. Jayant Naralikar, Dr. Fred Raab, Dr. Harsh Vardhan - Minister of Science & Technology and Prof. K.Vijay Raghavan - Principal Scientific Adviser, Government of India.

Top: *Along with the the Nikhef & LIGO-in-your-hands interferometer demonstrations, the 3D printed model (not to scale) of LIGO showed the main components of the detector.*

Bottom: *As part of the LIGO outreach week activities, GW experts from LISC institutes across India were delighted to present before this enthusiastic audience. Most hands were up to answer questions at the open quiz after the talk, highlighting the success of simplifying this complex subject in outreach activities.*

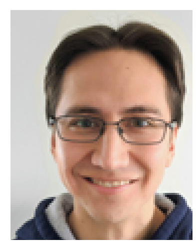
Improving the sensitivity of our future detectors

The current generation of large-scale laser-interferometric gravitational-wave detectors are now in operation and collecting data at unprecedented sensitivity and bandwidth. Strong R&D projects, which exploit the existing infrastructure, are currently underway. However, new facilities will be required to significantly improve the sensitivity of the detectors for the next phase of gravitational wave astronomy. Here we describe three of the proposed facilities which include the Neutron star Extreme Matter Observatory (NEMO), Cosmic Explorer (CE) and the Einstein Telescope (ET).



Artist rendition of the proposed Neutron star Extreme Matter Observatory in Australia.

Francisco Hernandez Vivanco
[on behalf of OzGrav]



Francisco is a third-year PhD student at Monash University in Melbourne, Australia. His work focuses on applying Bayseian inference to gravitational-wave observation to determine the properties of neutron stars. In his spare time, Francisco enjoys listening to heavy metal and playing video games.

Neutron star Extreme Matter Observatory (NEMO)

Neutron stars are some of the densest objects in the Universe, with the heaviest stars containing as much as two times the mass of the Sun in a region approximately the size of a small city. They offer a unique opportunity to understand the nature and interaction of matter at extremely high densities, conditions which cannot be recreated in Earth-based laboratories. This information is encoded in the neutron star's equation of state, which describes the dynamical properties of a neutron star such as pressure and density. Gravitational waves from such sources allow us to probe nuclear matter at an unprecedented level.

The current-generation gravitational wave (GW) detectors, such as advanced LIGO and Virgo (aLIGO and aVirgo) are sensitive in the frequency range from roughly 20-500 Hz. They primarily detect signals emitted during coalescence of binary neutron stars and binary black holes. Observations of GW signals from binary neutron star coalescences can also be used to constrain the equation of state. However, most of this information comes from frequencies above 500 Hz in the final stages of the coalescence. Researchers within the Australian Research Council Center of Excellence for Gravitational-Wave Discovery (OzGrav) are working on a design for a high-frequency detector to target these signals. The proposed detector, commonly referred to as the Neutron star Extreme Matter Observatory (NEMO), will have significantly better sensitivity over the existing aLIGO/aVirgo detectors above 500 Hz. With NEMO, we aim to probe the equation of state in two different ways: (1) by observing GWs emitted just before the two neutron stars merge, and (2) by measuring the GW emission from the remnant after the coalescence.

The gravitational interactions between the two neutron stars will induce a mutual deformation. This shows up as structure in the GW signal moments before the merger at frequencies above 500 Hz and varies depending on the "fluffiness" of each star. We can use this information to distinguish between different models for the neutron star equation of state. Additionally, the collision can result in the formation of a black hole or a hot neutron star. In the case of a hot neutron star, the GW emission is expected to show characteristic peaks at frequencies above approximately 1 kHz, where NEMO will be most sensitive. By measuring this peak frequency, we can understand the behaviour of the hot equation of state.

Considering both of these scenarios, we have shown that the addition of NEMO to a network of upgraded aLIGO detectors can place stringent constraints on the equation of state. This can be done at a fraction of the cost of a full next-generation detector and in a much shorter timescale. Simulations indicate that a network of NEMO and upgraded aLIGO detectors will enable us to constrain the radius of a neutron star to less than 1 km after only 6 months of observations. On the contrary, the existing aLIGO and aVirgo detectors will require one year's worth of observations to achieve similar results. Additionally, we find that adding NEMO to the network will increase the detection rate of the post-merger remnants to about 1 per year, as opposed to one every tens of years if we only upgrade the LIGO detectors. This “matter machine” will help us understand neutron stars at an unprecedented level. We hope that this idea will become a reality in the future and allow us to test new and exciting physics that we have yet to discover.

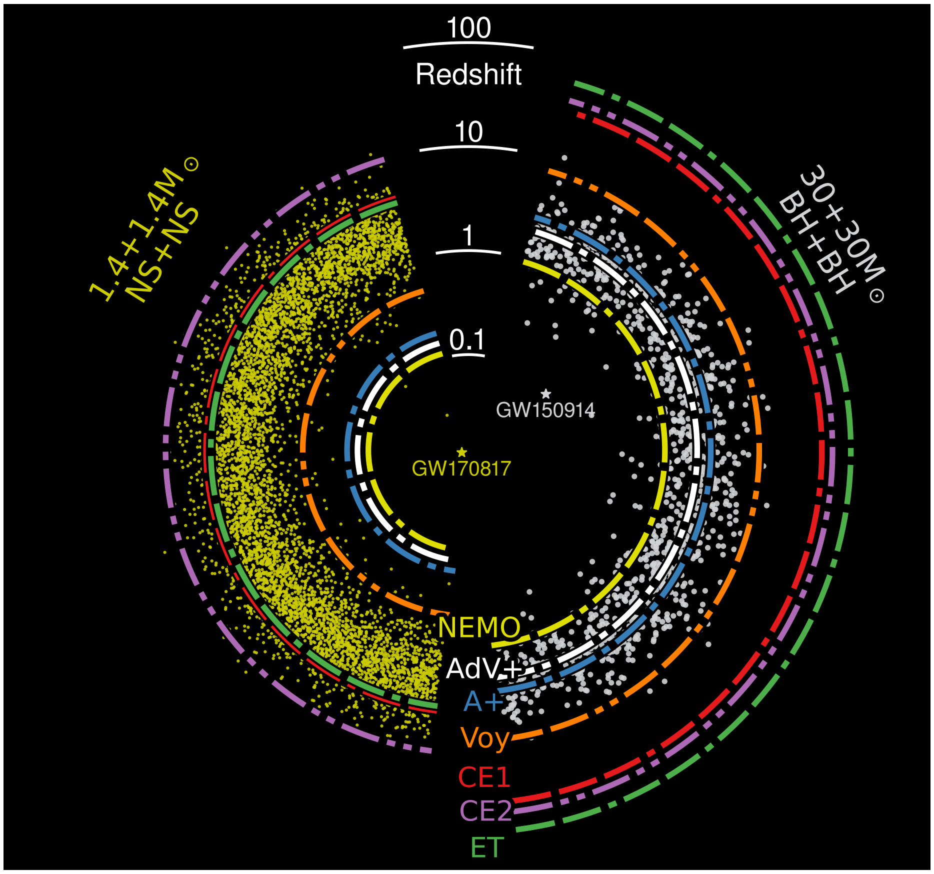
References

Ackley et al., Neutron Star Extreme Matter Observatory: A kilohertz-band gravitational-wave detector in the global network. arXiv:2007.03128 [astro-ph.HE]. https://arxiv.org/abs/2007.03128

Cosmic Explorer (CE)

In the past five years, the aLIGO and aVirgo detectors have discovered signals from over 65 compact binaries such as coalescing binary black holes (BBH), binary neutron stars (BNS), and possibly even neutron star black hole (NSBH) mergers. These detections have begun to provide deep insight into the astrophysics, population estimates, and dynamics of compact binaries. We now have a new tool for gaining a deeper understanding of the neutron star equation of state, kilonovae dynamics, and r-process nucleosynthesis. The discovery of a large number of BBHs has opened a new window to observational cosmology and allowed us to test general relativity at extreme spacetime curvature, which has never before been explored, and to rule out certain alternative theories of gravity invoked to explain dark energy.

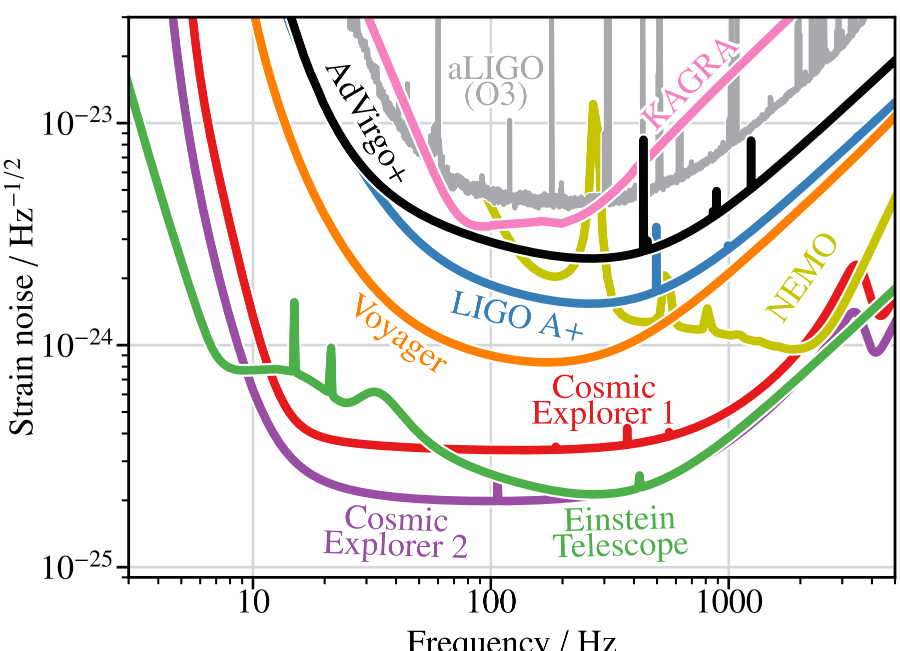
Detectability of compact binaries. The dots represent the distribution of compact binaries in the universe according to existing population models. The dashed contours represent the horizon of the sources that will be detectable by each detector. We will be able to sample the entire known population of compact binaries in our universe with third-generation detectors.



Varun Srivastava
[on behalf of the CE team]

Varun Srivastava is a graduate student at Syracuse who loves painting in his spare time. He works on a range of topics including piezo-based Suspended Active Matching Stage (SAMS), repurposed time-of-flight phase camera for wavefront sensing, heat budget for Cosmic Explorer 2 (CE2) and optimising the Cosmic Explorer design for post merger signals.

Cosmic Explorer (CE) is a proposed third-generation GW detector to be built in a new, approximately 40 km long L-shaped surface facility in the US. The National Science Foundation is funding an initial study into the science case for CE, its cost, and conceptual design, which should help determine the technology needed to accomplish the discovery potential of CE. Current plans are for CE to be deployed in two stages. The initial detector (CE1) is planned to be built in the 2030s mostly using the existing aLIGO technology such as a 1 µm laser and room-temperature fused silica test masses. The advanced detector (CE2) is planned for 2040s and will either involve iterating further on 1 µm silica technology or adopting another set of technologies, such as 2 µm lasers and cryogenically cooled silicon test masses as envisioned by LIGO Voyager. In all cases, CE will use heavier test masses, increased circulating arm power, and improved frequency-dependent squeezing to reduce quantum noise. To increase the sensitivity at low frequencies where environmental and thermal noise sources limit the performance, CE plans to take advantage of Newtonian noise suppression techniques, better active seismic isolation, and improved mirror suspensions. The existing noise budget suggests that these design upgrades, along with the longer arm length, will make CE over 10 times more sensitive than the current detectors.



Strain sensitivities of the current and future gravitational-wave detectors.

According to the current timeline estimates, CE will be observing in concert with Einstein Telescope (ET) and possibly a facility in Australia, to form a global network of third-generation GW detectors. This will have far-reaching consequences on our understanding of the universe. The significantly higher sensitivity of third-generation GW detectors will allow us to detect compact binaries in our local universe with an unprecedented signal-to-noise ratio (from 500 to 5000 or more depending on the source) and localize these events in the sky to within a few tens of square arcminutes. With hundreds of gravitational and electromagnetic observations of compact binaries, we would be able to better understand kilonovae dynamics for different compact binary populations and examine accretion dynamics around BBHs. Additionally, CE and ET observations will help resolve mysteries surrounding the structure of neutron stars, such as the equation of state and the post-merger oscillations of neutron star remnants. A catalog of almost every stellar-mass BBH merger in the universe would allow us to test general relativity at extreme curvatures and shed light on the origin of supermassive black holes, specifically if coalescing stellar BBH served as their seeds. These observations would revolutionize the field of astrophysics, cosmology, and fundamental physics. Learn more at https://cosmicexplorer.org/.

The Einstein Telescope (ET)

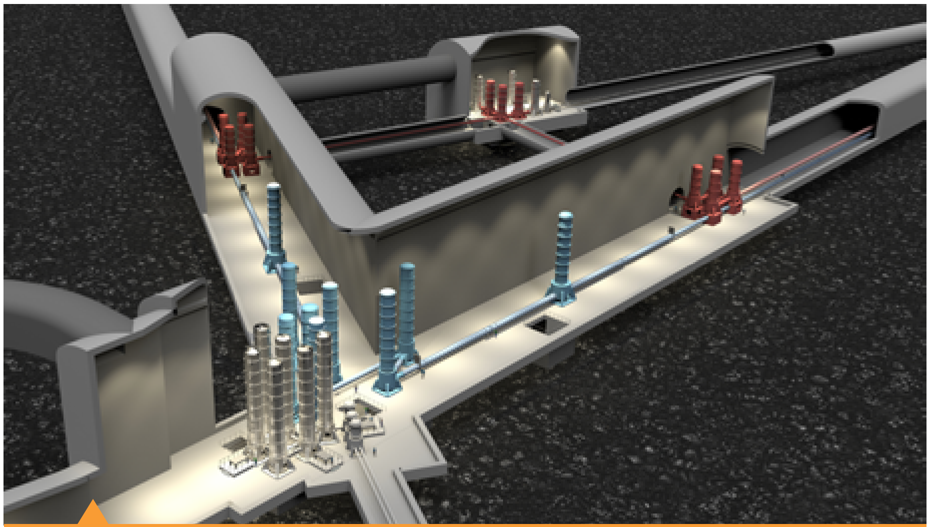
Andreas Freise
[on behalf of the ET team]

Andreas Freise is a Professor of Gravitational Wave Physics at the Vrije Universiteit Amsterdam and a member of Nikhef. He enjoys making things, and cheese sandwiches

The Einstein Telescope (ET) is a planned European third generation GW observatory, a new research infrastructure designed to observe the whole Universe with gravitational waves [1]. We have achieved extraordinary results with the aLIGO and aVirgo detectors. However, our success only marks the beginning of a new scientific era of GW astronomy. Third-generation (3G) GW detectors, such as ET, will improve the broadband sensitivity of the detectors by a factor of 10 and extend the sensitivity range to lower frequencies.

Ideally, ET would become part of a global network of several 3G detectors. However, it should make a leap beyond incremental updates of current detectors even as a single observatory. The ET design consists of a single underground infrastructure that hosts three detectors nested in an equilateral triangle with the sides being 10 km long. Each of the three detectors is composed of two interferometers, one being optimised for low-frequency signals, and the other for the high-frequency signals. These detectors together offer broadband sensitivity in the frequency range from a few Hz to about 10 kHz.

In September of 2020, the ET consortium has submitted an application for ET to be added to the European roadmap for research infrastructures. The first observations are expected to start in the 2030s. Two sites are still under consideration to host ET: Sardinia in Italy and the Euregio Meuse-Rhine (EMR) on the Belgian-Dutch-German border. Both sites already profit from EU and national funding targeted at a better understanding of the local geology and specific testbeds for new technologies required to make ET a success. In Italy, an underground facility at the Sos Enattos mine on Sardinia has been funded as well as a dedicated cryogenic facility [3]. In the EMR, a laser-interferometry R&D laboratory (ET Pathfinder) has been funded as well as a project for geology studies and a cold silicon mirror facility (E-TEST). Notably ET Pathfinder is envisaged to become the R&D laboratory for all next-generation GW detector technology and as such welcomes new collaborators.



Artist impression of the Einstein Telescope underground structure, showing one corner of the triangle with several caverns and vacuum vessels hosting the interferometer optics.

The anticipated science outputs of 3G observatories have been detailed in several reports and papers, with the details for ET having been updated recently in [3]. ET will surpass the best sensitivity of present observatories by an order of magnitude. Depending on source characteristics, ET will be able to track a GW signal from a binary neutron star merger for up to 24 hours, giving us plenty of time to alert electromagnetic telescopes to study such events in detail. The triangular layout, which houses multiple detectors, allows ET to operate as a stand-alone observatory with the capability to localise sources and resolve different GW signal polarizations even before other 3G detectors join the network. With ET, the coalescence of binary black holes (BBHs) will be visible out to redshifts of 20 and higher, thus allowing us to move into the realm of cosmology. The expected detection rates for BBHs coalescences will be on the order of 10^5-10^6 per year as well as 10^5 binary neutron star coalescences per year. This detector will also expand the range of detectable black-hole masses up to several thousand solar masses. Europe has a long tradition of building strong international collaboration. With ET we hope to create a new focus for gravitational wave science. If you want to become part of ET, please get in touch [4]!

References

[1] ET project webpage http://www.et-gw.eu

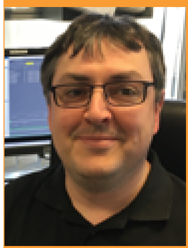
[2] ET Science Case 2020
https://arxiv.org/abs/1912.02622

[3] ET Pathfinder project webpage
https://www.etpathfinder.eu

[4] ET Steering Committee
http://www.et-gw.eu/index.php/et-steering-committee

The LISA mission in 2020: project status

Martin Hewitson



is a Staff Scientist at the AEI in Hannover and is currently leading the LISA Consortium's Coordination and Instrument groups. His research is focussed on all aspects of the LISA mission.

LISA will be a constellation of three spacecraft in a triangle configuration millions of kilometers apart. It will detect gravitational waves using laser interferometry (with six links), measuring changes in proper distance between freely-falling test masses on each spacecraft. Three years ago, the LISA mission proposal was selected as part of the European Space Agency's (ESA) scientific theme, "The Gravitational Universe", the third large mission planned for ESA's Cosmic Vision Programme. An upcoming major milestone is the Mission Adoption, the formal point in the programme where ESA's Science Programme Committee commits to the mission and the budget.

The LISA mission project status

ESA missions follow a standard development process with specific phases and milestones. LISA successfully passed the Phase 0 Mission Definition Review in December 2017 and moved to Phase A. At Phase A, a clear set of requirements are established for the mission, science, instrument, spacecraft and ground segment. In November 2019, LISA passed the Mission Consolidation Review, confirming the capability of the proposed design to meet the mission requirements.

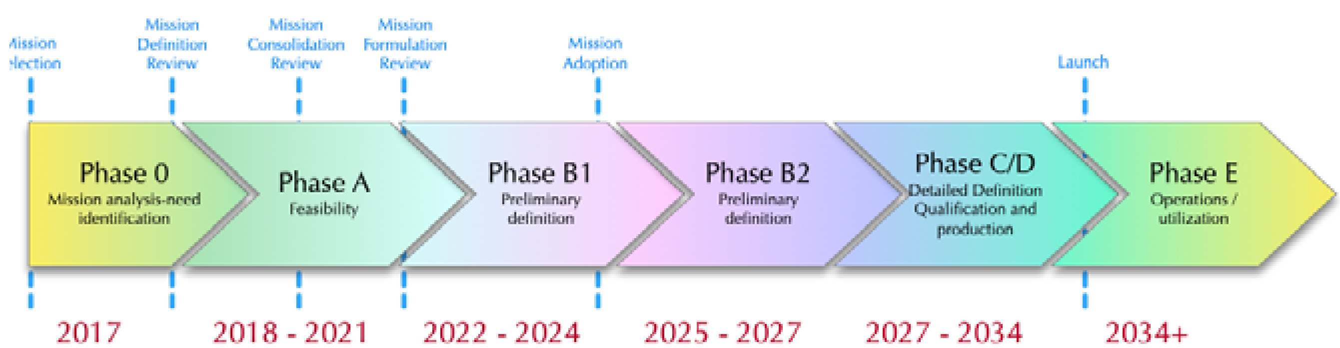
The LISA Consortium, an international collaboration of scientists and engineers, focuses on the management and development of deliverable elements from the European National Space Agencies, ESA, and NASA, ranging from hardware units through data analysis, computing infrastructre and data products. NASA is a junior partner contributing to certain hardware elements as well as ground-segment and science expertise.

The phases and timing of the LISA mission programme at the time of writing.

Recently, an agreement was reached between the European national member states and ESA to transfer some of the instrument system engineering responsibility from the Consortium to ESA. This will establish a clearer system engineering flow between the critical elements of LISA. This shift of responsibility necessitates an extension to the Phase A during which ESA, the industrial teams performing the study, and the Consortium, can work towards establishing this baseline. Following Phase A, the mission will enter Phase B1 during which development and demonstration of critical hardware will continue, and the mission design will be consolidated.

Technological Development

The path towards Mission Adoption is dominated by two key aspects: to establish all key requirements and their interdependencies, and to do pre-development of all critical units up to what is called Technology Readiness Level 6. This means that a number of units have to undergo prototyping and development to confirm the capability



to provide the necessary functionality and to demonstrate key performance aspects under the expected environmental conditions. A number of these critical units have already been identified, and a number of developments are already well underway in the Consortium, ESA and NASA. By the end of Phase A, a solid development plan will have been established, and all critical units will have been identified, paving a clear path towards the mission adoption. This forms the beginning of the implementation phase (B2/C/D).

In this article, we look at some of these key developments, and report on the progress and plans from the LISA Consortium side.

• Optical Bench

The Optical Bench (OB) is the heart of LISA's interferometric measurement system. OBs on each spacecraft host three interferometers which: 1) measure motion between the spacecraft with respect to the laser wavefront from a distant spacecraft; 2) measure motion between a free-falling test mass with respect to the OB itself; and 3) act as a phase reference between the two lasers on the host

Dave Robertson

David Robertson works in Glasgow University where he builds low-frequency interferometers. In his spare time he enjoys running up small mountains with like-minded friends

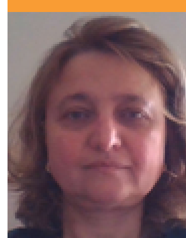
spacecraft emitted along the two arms originating from each spacecraft. There are 18 interferometric measurements over the constellation, as well as auxiliary measurements monitoring processes such as data transfer etc. These measurements will be fed into an on-ground process to combine all the data and produce the science observables to be analysed.

Around 10 complete OBs will be built (2 in each of the three satellites, 2 development models, and 2 spares) at a dedicated facility being built at the UK Astronomy Technology Centre in Edinburgh. A semi-automatic bonding process developed at the University of Glasgow will be used to attach components to the baseplate.

• Quadrant Photoreceivers

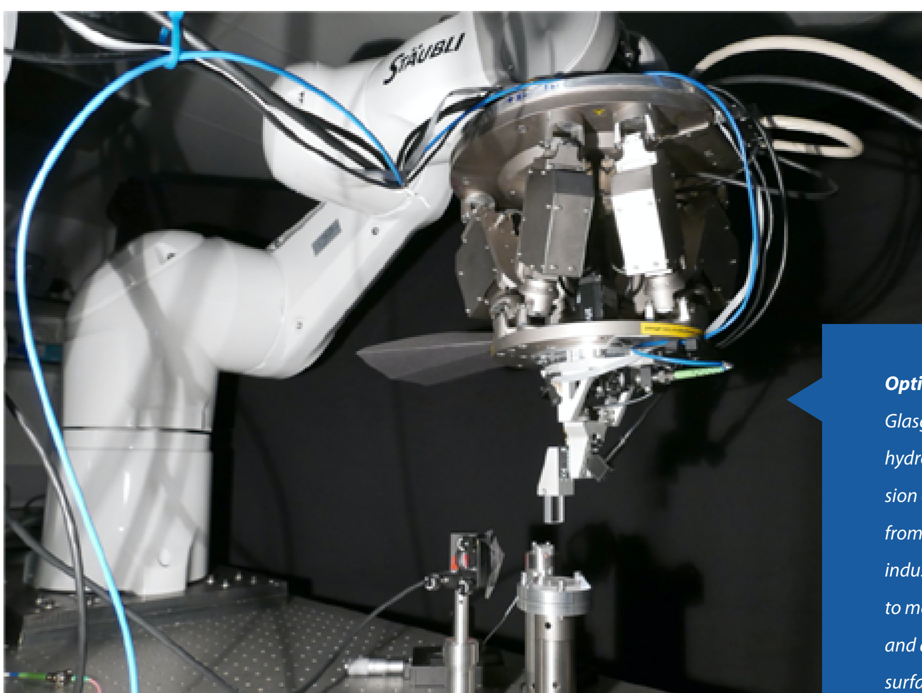
The Quadrant Photoreceivers (QPRs) are optoelectronic components responsible for the optical read-out of the LISA interferometric signals. A total of 120 QPRs will be required (including flight, development and spares), meaning 12 QPRs on each OB model. Each QPR features three main components: 1) an InGaAs quadrant photodiode (QPD) with four segments, aiming to convert the optical signal into a photocurrent; 2) a front-end electronics (FEE) with the main goal of amplifying each QPD segment's photocurrent and converting it into voltage; 3) a mechanical enclosure aiming to provide precise and stable positioning of each QPD with the optical beam, to assure the electromagnetic compatibility of the QPR and to assembly the QPD and the FEE in a limited volume allocated on the OB.

Nicoleta Dinu-Jaeger



is Research Engineer at ARTEMIS Laboratory/ Côte d'Azur Observatory, Nice, France. She is co-leader of the LISA QPR working group and an expert on photodetectors for visible and infrared light detection.

Experts from AEI (Germany), SRON and NIKHEF (Netherlands), KU Leuven (Belgium), ARTEMIS (France), UK-ATC and University of Glasgow (UK) and JAXA (Japan) are working in close collaboration to find the best solution for the QPD, FEE and mechanical enclosure of the LISA QPR.

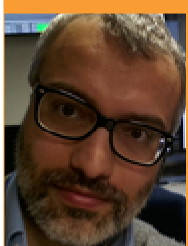


***Optical bench:** Prototype positioning system in use at the University of Glasgow. The system allows an optical component to be automatically hydroxide-catalysis bonded anywhere on the optical bench with a precision of 4 micrometers and 10 micro-radians. The component is mounted from a hexopod for fine control and the assembly mounted on an industrial robot arm for wide range movement. Interferometery is used to measure the separation and alignment of the surfaces to be bonded and a separate probe beam measures position and angle of the optical surface. An integrated control system automates most of the process.*

• Phasemeters

The LISA phasemeter processes the outputs of the different interferometers on each optical bench. Its measurements are used for spacecraft and test mass position and attitude control, as well as being the primary data signals that are analysed on ground in a process called Time Delay Interferometry. In addition, the phasemeters have to perform a set of other critical auxiliary functions, such as optical data encoding/decoding, clock-noise transfer, and laser transponder locking. The LISA phasemeter is a German National contribution in cooperation with Denmark. It builds on previous phasemeter developments, such as those for the Grace Follow-on mission.

Luigi Ferraioli



is leading the Aerospace Electronics and Instruments Laboratory at ETH Zurich. He is co-chair of the LISA LDPG Simulation working group.

• Gravitational Reference Sensor

In LISA, the proper motions of two freely-falling test masses (millions of kilometers apart) contain the information we want to extract about passing gravitational waves. This information is measured by the Gravitational Reference Sensor (GRS), the technology for which was demonstrated by the LISA Pathfinder mission. Italy led the development of the GRS for LISA Pathfinder, and will do so again for LISA. The sensing and control electronics for the GRS are a Swiss contribution to the LISA mission and ETH Zurich is currently working on the instrument requirements.

Over time, the freely-falling test masses will become charged and need to be discharged using ultraviolet (UV) light. A method using UV LEDs, similar to that used in LISA Pathfinder, is being developed by the University of Florida under a NASA contract.

• Telescopes

Each LISA spacecraft contains two telescopes which act as two-way beam expanders. The telescope magnifies the laser beam as it leaves the spacecraft, optimizing it for delivery to another spacecraft. After millions of kilometers, the beam is several kilometers wide and only a fraction is intercepted by the receiving spacecraft. The telescope then acts to compress the intercepted beam, making it ready for delivery to the optical bench. Eight flight model telescopes will be required (6 + 2 spares) as well as a number of development models. These are being developed by NASA's Goddard Space Flight Centre together with industrial partners.

• Lasers

To complete the optical measurement system, we need light sources. On LISA, this comes in the form of 6 laser systems (2 per spacecraft), each with internal redundancy, meaning a total of 12 laser heads. Each laser system shall deliver 2 Watts of linearly polarised phase-coherent light at 1064 nanometers. One of the lasers in the constellation acts as a primary reference and is locked to a highly stable optical cavity to stabilise its frequency. The other 5 active lasers are locked to the primary reference. These lasers have very stringent requirements on frequency and amplitude stability, as well as lifetime. The laser systems are under development by ESA and NASA.

Jean-Charles Damery

is Engineer in CNES (the French space agency). He is the Project Manager for the french participation in the LISA project.

• Assembly, Integration, Verification and Test

The Moving Optical Sub-Assembly (MOSA) consists of a telescope operating in transmission and reception, an optical bench, and a gravitational reference mass all integrated in an ultra-stable structure (MOSA Support Structure). Eight MOSAs will be produced (including 2 spare models). In addition two test models will be needed, meaning no less than 10 models will need to be assembled and tested before 2031.

One of the test models, the Structural and Thermal Model (STM) will verify the critical thermo-mechanical properties of the structure and components. The other, the Engineering and Qualification Model (EQM) will be used to verify function and performance of the instrument, including environmental tests in vacuum. After STM and EQM testing, the first flight model will be constructed and the rest of the flight models (5 MOSA) and the spares (2 MOSA) will follow in a kind of MOSA "factory" or production line / assembly line. Integrating and testing the MOSA is being led by CNES in France.

• Astrophysics & Cosmology with LISA

LISA is expected to observe a wide variety of gravitational wave sources in the millihertz frequency band. These include the mergers of massive black hole (MBH) binaries, the extreme-mass-ratio inspirals (EMRIs) of stellar origin black holes (SOBHs) into MBHs, double compact object binaries with hour-long orbital periods in the Milky Way, mergers of SOBH binaries similar to GW150914, at the high end of the mass range probed by LIGO and perhaps a stochastic gravitational wave background produced in the early Universe. These observations will permit a wide range of scientific investigations, ranging from learning about the population of galactic compact binaries, to probing the assembly of the MBH population and their stellar environments in the local Universe, to understanding the origin of SOBH binaries and finally to tests of fundamental physics and probes of cosmology.

Over the past year, the LISA Science Group (LSG) was tasked to investigate the impact on the delivery of these science objectives of two different aspects of the LISA mission configuration.

The first investigation concerned low-frequency sensitivity. The original LISA mission proposal has a requirement on the LISA sensitivity at 0.1 milliHertz, but only a goal at lower frequencies. ESA requested that all goals be either removed or replaced with requirements. Extending the low frequency sensitivity would, for example, increase the length of observations for more massive MBH binaires (improving their sky location measurements and prospects of finding electromagnetic counterparts), allow tests of the no-hair property of black holes (through detection of more ring-down modes) and improve prospects for detection and characterising the stochastic gravitational wave background. The LSG recommendation was to place a requirement on LISA sensitivity at 50 mHz, but the ESA Science Study Team (SST) concluded that the scientific case was not sufficiently compelling to outweigh the significantly increased costs of guaranteeing the low-frequency sensitivity. LISA will have sensitivity in the 0.01 – 0.1 mHz range, but the actual performance

Jon Gair

is a Group Leader in the Astrophysical and Cosmological Relativity division at the AEI in Potsdam. He currently chairs the LISA Science Group.

at the low-frequency end will not be known until the observatory is finally operated.

The second study concerned the mission duration. The initial proposal was a 4 year mission. The impact of mission duration on the science output depends somewhat on the source of the gravitational waves. For example, galactic compact binaries or EMRIs are slowly evolving or monochromatic and a longer observation period is beneficial. An important element in this study was to investigate data gaps. LISA is expected to have gaps when useful data is not being collected. Some of these will be planned, e.g., for telescope repointing, but others will be unexpected. Based on experience with LISA Pathfinder, which had a ~90% duty cycle (the percentage of time collecting useful data), we might expect LISA's duty cycle to be ~75% (for three independent spacecraft). Approximately speaking, the effect of data +gaps is equivalent to having a shorter mission duration. The conclusion of the LSG study was that all of the LISA science objectives all of the LISA science objectives would benefit from an increased mission duration of 6 years, and in particular the prospects of observing SOBH binaries in conjunction with LIGO are significantly improved. The ESA SST has recommended that ESA explore the implications of an increased mission duration. Once again, however, it is expected that the LISA mission will have an extended mission period after the initial mission duration, and will be collecting data around ten years in total.

Acknowledgements

SRON and Nikhef acknowledge support from the Dutch Research Council (NWO) for their LISA-QPR effort.

The LISA Japan instrument group acknowledges the support by the Advisory Committee for Space Science in the Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency (JAXA).

The Albert-Einstein-Institut acknowledges the support of the German Space Agency, DLR. The work is supported by the Federal Ministry for Economic Affairs and Energy based on a resolution of the German Bundestag (FKZ 50OQ1801).

ETH Zurich acknowledges the support of the Swiss Space Office SSO (State Secretariat for Education, Research and Innovation SERI) via the PRODEX Programme of ESA and of the Swiss National Science Foundation (SNF 200021_185051).

Diversity in the LIGO and Virgo Collaborations

A lack of diversity in the sciences is a long-standing problem both in the wider scientific community as well as within our own collaborations. We hear from Ray Frey and Tania Regimbau on the diversity efforts within our collaborations and plans for the future. Ray Frey is the chair of the LIGO Scientific Collaboration (LSC) Diversity Committee and Tania Regimbau is the Virgo Collaboration Diversity Chair.

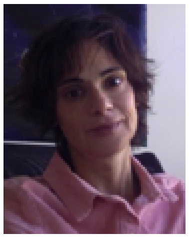
Ray: First, a bit of history. In the LSC, the Diversity Committee (DC) has only become an official body in the last few months with the approval of the revised LSC bylaws. Patrick Brady, the LSC Spokesperson, asked me to chair the committee for its first year. Previously there was a "diversity group" in the LSC, which essentially consisted of a Chair and a mailing list. An early success of the diversity group was to take a census of diversity within the LSC. Not surprisingly, this census mirrored the general situation in STEM fields: Women and other under-represented (UR) groups are woefully short of their representation in society. Following the 2013 census, the group were informed that such data mining was on shaky legal ground and were advised to end it. Since then, the group has largely focused on providing diversity-related educational segments at the LIGO-Virgo collaboration meetings.

Tania: The Virgo diversity group was formed in 2014, in close relationship with the LIGO diversity group. Their first action was to create a family grant to LIGO-Virgo meeting support participants with accompanying children at the March 2014 meeting. Then in October 2014, the document "Non-discrimination and anit-harassment guidelines for the Virgo collaboration" was written. It provides a clear definition of harassment, states the Virgo anti-harrassment and discrimination policy, defines the role of the Ombundsperson, and includes information on how to report harassment. The Ombundsperson provides confidential, informal, independent, and neutral dispute resolution advisory services for all members of the Virgo collaboration. They should not hold any other leadership or supervisory roles that may compromise their impartiality, and they report only to the Virgo Spokesperson, but do not share any confidential information.

Raymond Frey

(who usually goes as Ray) is a Professor of Physics at the University of Oregon and has worked as a high-energy experimentalist on projects at CERN, SLAC and Fermilab, among others. Since 2010, Ray has worked full time on gravitational waves and the LSC, chairing several working groups and committees including Gamma Ray Bursts, Publications and Presentations, and Bursts.

Tania Regimbau



is director of research at the French National Center for Scientific Research. Tania has worked on a variety of topics from gravitational wave emission from galactic neutron stars to the gravitational wave stochastic background and has been the chair of the Virgo stochastic group since 2012 and the Virgo Diversity Coordinator since 2018.

Ray: Looking forward to the new LSC DC, there is now a chance to press "reset" and it is certainly timely to pursue this aggressively! The first task is to find committee members.

Tania: The Virgo Spokesperson has approved that gender will be added to the Virgo database. This will allow us to study gender bias statistics for the first time within the collaboration. Collecting other information, like ethnicity, religion or sexual orientation is against the law in many European countries, which is very understandable if we consider the history.

Ray: In moving forward, it is important to understand what the DC can effectively do, and what they cannot. For example, the LSC is not involved in personnel issues, e.g. hiring or promotion. But what it does have power to control is the membership and leadership of its many committees and organizational structures. The DC has a definitive role in suggesting members of UR groups for leadership positions. We feel that it is important to augment our decision-making bodies, such as publication editorial teams, with members from UR groups and from smaller LSC groups. As such, the new bylaws explicitly place one member of the DC on the Speakers and Awards Committee and a liaison on the LSC Academic Advisory Committee.

Tania: In July 2020 a Virgo diversity mailing list and a LGBTQ+ mailing list were created, with a wiki page containing important document links to related diversity issues and proposed solutions. For the first time, we will have a diversity session at the next Virgo meeting week.

Ray: Our task as the DC is now to develop "quantitative goals" for the LSC and a best practices guide, and to maintain these on at least an annual basis. Of course, the DC can do more than what are the minimum requirements, just as we all can (and should) do more to work on issues of social injustice. We are excited to get this started!

Lucía Santamaría: From data analysis to machine learning

Lucía Santamaría is an Applied Scientist in machine translation at Amazon lucia.santamaria@ymail.com

It was my interest in General Relativity and programming as an undergrad that prompted me to pursue graduate studies in the field of Numerical Relativity (NR), initially in Jena and later at the Albert Einstein Institute in Potsdam. I joined LIGO in 2007 and worked on incorporating NR simulations of the late inspiral, merger, and ringdown phases of black hole binaries as templates into the gravitational-wave analysis pipeline used to search for inspiral signals. This work eventually led to my PhD thesis, after which I accepted a postdoctoral appointment at Caltech to continue working on data analysis for LIGO.

My time in LIGO was extremely rewarding, both personally and professionally. However I had the usual concerns about the feasibility of reaching a permanent position in a finite number of years. In 2011 I decided to look for opportunities besides academia and leveraged my technical skills to find a job at a bibliographic service for scientific publications.

The progression to data science was a natural one given my background - let's not forget that data scientist was labelled "the sexiest job of the 21st century"[1] and seemed to be the optimal fit for math and physics doctorates looking to avoid the eternal postdoc stage.

While I initially focussed on business analytics and descriptive statistics, I soon found problems related to machine learning to be more challenging and interesting. For a while I worked in the field of recommender systems, which aims at predicting the rating or preference that users give to certain items. Eventually I landed my current position as Applied Scientist in machine translation at Amazon.

Machine translation, a subfield of computational linguistics, deals with the task of converting source text or speech from one language to another by means of fully automated software. This research area has undergone a revolution over the past few years: statistical machine translation, which had dominated the field for over half a century, has been recently superseded by neural machine translation, a deep-learning approach based on recurrent neural networks.

Needless to say, the field is very active and vibrant. In my role as Applied Scientist I get to employ state-of-the-art machine translation research to localize millions of Amazon products into multiple languages. I am encouraged to stay in touch with current literature and publish my findings at topical conferences. At the same time, the job requires me to be hands-on with code design and implementation. Finally, the fact that we can instruct a computer, via a programming language, to understand natural language still blows my mind! I find computational linguistics highly intriguing and captivating.

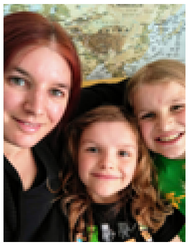
In truth I never actually designed my post-LIGO career to bring me where I am now. Over the years my motto has been "if there's lots of data and I can write code to deal with it, I'm interested". My curiosity and drive for problem-solving remains the same as it was during my time with LIGO. Everything I learned working in data analysis for gravitational-wave signals has served me well ever since, and for that I am deeply grateful to the wonderful community I once was a part of. If only, I miss not having been around for the exciting detection of the GW190521 intermediate mass black hole!

LIGO 2020

[1] Harvard Business Review hbr.org/2012/10/data-scientist-the-sexiest-job-of-the-21st-century?

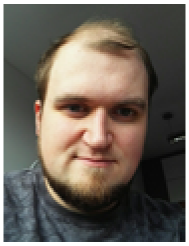
Collaboration papers: contribution & acknowledgement

Jessica Steinlechner

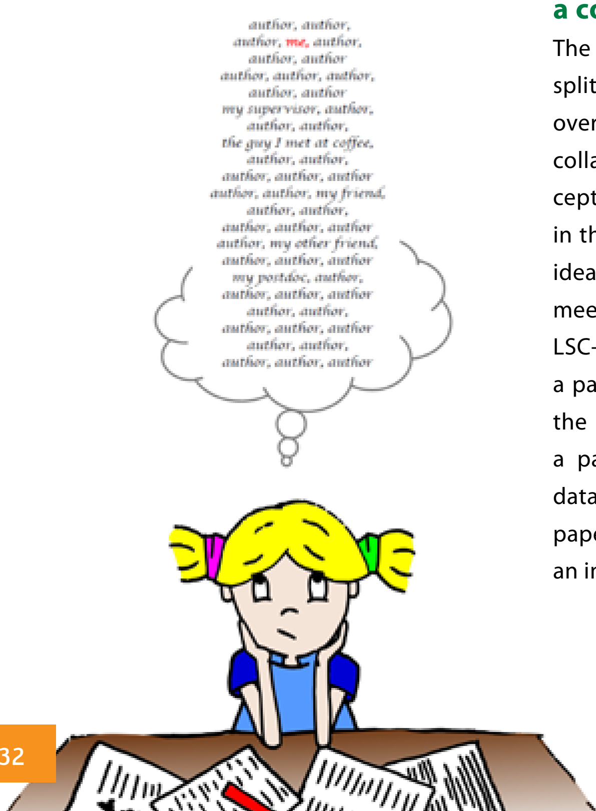


is an assistant professor at Maastricht University in the Netherlands. Her research focuses on the development of mirror coatings. Over the past months she shared the home office with her two children.

Mikhail Korobko



is a postdoc at the University of Hamburg in Germany. He studies quantum limits on the sensitivity of gravitational-wave detectors and the ways to surpass them using quantum correlations. His free time is dedicated to raising two kids and occasional attempts to learn SciComm.



Publications with long author lists are one of the features of large collaborations. In the LSC (LIGO Scientific Collaboration), the full author list consists of around than 1000 scientists from over 100 different institutions. We earn authorship by spending a certain amount of our research time on developing and operating the detectors or analysing their data. When the collaboration publishes a result from the detectors, all the 1000+ people become authors of this publication. However, it is obvious that only a subgroup prepares the data for publication and actually writes the manuscript. Two main questions arise from this which are of particular interest for early-career scientists:

"How can I contribute to writing a collaboration paper?"

The LSC is organised in divisions, which are split into working groups. You can find an overview in LIGO document M1200248. A collaboration paper begins its life as a concept in one of these working groups, usually in the Observational Science division. Each idea is first presented in internal telecon meetings of the working group, and later in LSC-wide telecons. Once a topic is decided, a paper writing team is formed (usually by the working-group chairs), which includes a paper project manager, and teams for data analysis, writing and review. Once the paper reaches a mature state, it undergoes an internal collaboration review and is then circulated for comments from the whole collaboration. After collecting the reviews and comments, the final draft is presented to the collaboration following which the paper is finally ready to become public. It might take as long as 6 to 12 months from the first idea for the paper to go through all stages of the writing process. Details of this process can be found here: wiki.ligo.org/PPComm.

As an LSC member, there are several stages where you can contribute to a collaboration paper. The first is to become part of a writing team. This includes both senior and junior members, such that the experience and practical input is balanced. Usually the writing team is composed of members of the observational science working (sub-) groups, but some input from instrumental science is often essential too. Whatever group you belong to, if you are interested in joining a writing team, approach your supervisor or the working-group co-chairs who assemble paper writing teams.

Another step where your contribution is really valuable is the internal circulation of the paper. The paper writing team relies on feedback from the collaboration, and providing this is a great way to become an active co-author of a publication.

While it is never too early to become active and to get involved in these procedures by yourself, it is the responsibility of your ad-

Welcome to the LAAC Corner!
The LSC Academic Advisory Committee helps students and postdocs to learn more about LVK, find useful information and collaborate. In this article series we will discuss topics of particular interest for young researchers within our collaboration. Let us know if you have wishes for themes!

If you have any questions or comments, please visit our website:
laac.docs.ligo.org
the LAAC wiki: wiki.ligo.org/LAAC
or email us: LAAC@ligo.org
Have fun reading!

Paul Fulda & Jessica Steinlechner,
LAAC co-chairs

viser to make sure that you participate in publishable work - not only in the paper-writing procedure, but also in the actual research. Therefore your adviser is the best person to approach if you are interested in getting involved in projects outside your current activities.

"How can I get acknowledged for my contribution?"

The full author list is always in alphabetical order and the LSC policy does not allow for a highlighted position of individuals. Publications in some journals require an "author contribution" section. The current policy states that "all authors significantly contributed", e.g. see here: nature.com/articles/nature24471.

While this is in the spirit of acknowledging everyone's contribution, the question of how you can get acknowledged for your individual work becomes very important, especially if your research offers little opportunity for short-author list papers. Presenting the result at a conference is a good way to show your connection to it, and the Speakers Board may help coordinate that.

If you apply for a job or a grant, highlight your contribution to collaboration papers, e.g. by marking certain collaboration papers and writing a short paragraph about your contribution. You can also ask your colleagues and supervisors to point out your contribution in their recommendation letters. Other options to get your contribution recognized can be found on our wiki page: https://wiki.ligo.org/LAAC/ContributionRecognition.

To make your contribution visible within the collaboration, ask your working-group chair or paper writing team if you can present the paper draft in a collaboration-wide (online) presentation or at a LIGO-Virgo-KAGRA meeting. Make it clear to the responsible people that you are interested and available for presentations!

The collaboration is always looking for ways to acknowledge and highlight individual contributions. Do not hesitate to talk to your group leader or working group chair about getting this acknowledgement - it will be important for your career.

LIGO 2020

Career Updates

Aaron Jones defended his PhD thesis "Impact and mitigation of wavefront distortions in precision interferometry" and recently moved from the University of Birmingham to a postdoc position at University of Western Australia.

Andreas Freise and **Conor Mow-Lowry** have moved from the University of Birmingham and joined Nikhef and the Vrije Universiteit (VU) Amsterdam as faculty members to start a new group, continuing their work on design and instrumentation for gravitational wave detectors. Andreas was appointed professor of Gravitational Wave Physics. Andreas and Conor have joined the Virgo collaboration and they have been approved as a new LSC group.

Bhavna Nayak successfully defended her thesis "Characterizing Crystallization in Nanolayered Dielectric Coatings Annealed at High Temperatures" and earned an M.S. in Physics from California State University, Los Angeles in May 2020.

Christophe Collette has received an ERC consolidator grant (2 M€) dedicated to low frequency seismic isolation. Christophe also tells us about the start of another project dedicated to Einstein Telescope started recently (15M€), to develop a model of the underground in the Belgium-The Netherlands-Germany region, which is one site candidate for hosting ET and to develop a prototype for validating the ET technologies.

Christopher Berry has started a new lectureship position at the University of Glasgow. He will continue as research faculty at Northwestern University part-time for the 2020/2021 academic year.

Colm Talbot successfully defended his dissertation at Monash University. He has started a postdoctoral position at Caltech.

Daniel Holtz was elected to the Chair-line of the APS Division of Astrophysics.

Evan Goetz joined the gravitational wave astrophysics team and the LSC group at the University of British Columbia as a research associate in October, 2019.

We hear that ...

Career Updates

Hsin-Yu Chen will be moving from Harvard to MIT as an NASA Einstein-MIT Kavli Institute Fellow after the summer.

Jordan Palamos (U Oregon) successfully defended his thesis "Search for Gravitational Wave Signals Associated With Gamma-ray Bursts During LIGO's Second Observing Run".

Katie Rink graduated from the University of British Columbia with a B.Sc. in astronomy and a minor in physics in May 2020. Starting in the fall, she will pursue her master's degree at UMass Dartmouth working on numerical relativity simulations for LISA, and she plans to continue working with the UBC LIGO DetChar group during her graduate studies.

Maryum Sayeed graduated from the University of British Columbia with a Combined Honours in Physics & Astronomy B.Sc. degree in May 2020. She will be putting her LIGO data analysis skills to work in the technology consulting sector in Alberta.

Maya Fishbach (UChicago) received her PhD and was awarded a NASA Einstein Fellowship, which she will be taking to Northwestern University.

Mikhail Korobko has defended his PhD thesis in the University of Hamburg on the topic "Taming the quantum noise: How quantum metrology can expand the reach of gravitational-wave observatories". He will remain in the group of Roman Schnabel as a postdoc.

Miriam Cabero Mueller joined the gravitational wave astrophysics team at the University of British Columbia as a postdoctoral fellow in October, 2019.

Thomas Harris (Whitman College) completed his LSC work and undergraduate senior thesis on "A Data Mining Approach to Fscan Data" with his mentor Gregory Mendell in May 2020. Thomas will start graduate school in Applied Physics at the University of Oregon in the fall.

The GT numerical relativity group, led by **Deirdre Shoemaker** and **Pablo Laguna**, is moving to the University of Texas at Austin. They are starting a new center – the Center for Gravitational Physics. This new center will have Shoemaker (Director), Laguna, **Matzner** and Zimmerman. LSC members **Deborah Ferguson** and **Jacob Lange** will join forces with **Aaron Zimmerman**'s LSC group.

Three graduate students at Universitat de les Illes Balears successfully defended their PhD theses. **Antoni Ramos Buades** with "Gravitational waves from generic binary black holes: From numerical simulations to observational results", **Cecilio García Quirós** with "Waveform Modelling Of Binary Black Holes In The Advanced LIGO Era" and **Josep Blai Covas Vidal** with "Searching for continuous gravitational waves with Advanced LIGO".

Steve Eikenberry was named Undergraduate Teacher of the Year for the College of Liberal Arts and Sciences at University of Florida

The book 'Gurutviya Tarang - Vishwadarshanaache nave saadhan' (Gravitational Waves - A new window to the universe) co-authored in the Marathi language by **Ajit Kembhavi** and **Pushpa Khare** was awarded the Maharashtra state government's Mahatma Jyotirao Phule Award under the 'Science-Technology for adults' category.

Vijay Varma was awarded a Klarman Fellowship at Cornell, where he will spend a year before starting as a Marie Curie Fellow at AEI, Potsdam for two years.

Awards

Amanda Farah (UChicago) was awarded an NSF Graduate Student Fellowship.

Brian Metzger has been named the 2020 Blavatnik National Awards Laureate in Physical Sciences and Engineering, one of the Blavatnik Awards for Young Scientists.

Karan Jani was featured in the Forbes 30 under 30 All-star Alumni, and was awarded the title of Postdoc of the Year by Vanderbilt University.

Lynn Cominsky, Gabriela González, Vicky Kalogera, Brian Metzger and **Rainer Weiss** were named as five of the 200 inaugural Legacy Fellows by the AAS.

Mike Zevin (Northwestern) was awarded a Hubble Fellowship, which he will take to U Chicago.

Nancy Aggarwal was awarded the 2019 GWIC-Braccini Thesis Prize for her thesis, "A room temperature optomechanical squeezer".

Nutsinee Kijbunchoo won the 2019 International Wiki Science photo Competition, as well as the U.S. Jury's choice award, for her photograph of Georgia Mansell and Jason Oberling inside the H1 PSL enclosure. The winning photo is on p.35.

Siyuan Ma was awarded the Otto Hahn Medal for his PhD thesis on black-hole space times.

New LSC positions

Chad Hanna was elected as Co-Chair of the Compact Binary Coalescence group.

Karl Wette was re-elected as Co-Chair of the Continuous Wave group.

Raymond Frey was re-elected as Co-Chair of the Burst group.

Shivaraj Kandhasamy was elected Co-Chair of the Stochastic group. He succeeded Joe Romano as one of the co-chairs.

Vicky Kalogera was elected as one of the elected members of the LIGO Scientific Collaboration Management Team.

Other News

CSIRO's Parkes radio telescope 'The Dish', has been added to the Australian National Heritage List of natural, historic and Indigenous places of outstanding significance in Australia.

LIGO and gravitational wave detection have been featured on the **front cover** of the Maharashtra board Class XI physics textbook used by high school students in the state of Maharashtra, India.

The **Albert Einstein Institute** celebrated the 25th anniversary of its opening on 1st April 2020. https://bfschutz.com/2020/04/01/25-years-of-the-aei/

Long-time LIGO Magazine readers will remember **Riccardo DeSalvo**'s article in Issue 9 on "Hans Bethe's last prediction" about how binary stars evolve into black-hole neutron star systems, before merging to produce gravitational waves. Riccardo contacted us to remark about how such a source may have finally been detected: "[F]inally, GW190425 may well be a **"Bethe" event**, and we may find a few more in the rest of O3. Hans would be delighted! He would tell that GW190425 is a present from Nature, the same way he did when I went to look for him to tell him about 1987A!"

The LIGO-Virgo Cafe Press site now features a **high-quality mask with the LV logo** on it as well as the waveforms from GW150914. Each purchase from the Cafe Press site generates a small amount for a fund that supports the EPO activities. The main Cafe Press site is: https://www.cafepress.com/ligosc . The direct link to the mask is: https://www.cafepress.com/ligosc.552550518. Each mask comes with filters as well as adjusters for the ear loops.

LIGO 2020

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 also gratefully acknowledge the support of LSC related research by these agencies as well as by the Council of Scientific and Industrial Research of India, Department of Science and Technology, India, Science & Engineering Research Board (SERB), India, Ministry of Human Resource Development, India, the Istituto Nazionale di Fisica Nucleare of Italy, the Spanish Ministerio de Economía y Competitividad, the Conselleria d'Economia i Competitivitat and Conselleria d'Educació, Cultura i Universitats of the Govern de les Illes Balears, the European Union, the Royal Society, the Scottish Funding Council, the Scottish Universities Physics Alliance, the Hungarian Scientific Research Fund (OTKA), the National Research Foundation of Korea, Industry Canada and the Province of Ontario through the Ministry of Economic Development and Innovation, the Natural Science and Engineering Research Council Canada, Canadian Institute for Advanced Research, the Brazilian Ministry of Science, Technology, and Innovation, Fundação de Amparo à Pesquisa do Estado de Sao Pãulo (FAPESP), Russian Foundation for Basic Research, the Leverhulme Trust, the Research Corporation, Ministry of Science and Technology (MOST), Taiwan and the Kavli Foundation.

Online ISSN: 2169-4443
World Wide Web URL: https://www.ligo.org/magazine
Publisher: LIGO Scientific Collaboration, Pasadena, CA, USA
LIGO DCC: LIGO-P2000356
Contact: magazine@ligo.org

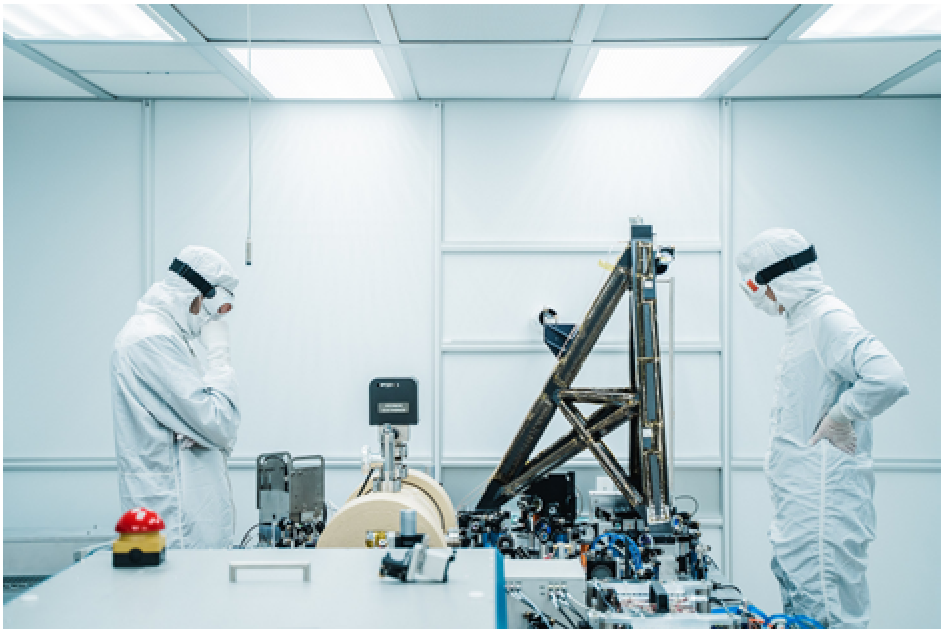
Editor-in-Chief: Hannah Middleton

Editors: Kendall Ackley, Deeksha Beniwal, Laura Cadonati, Andreas Freise, Tobin Fricke, Paul Fulda, Gabriela González, Anna Green, Amber Strunk Henry, Nutsinee Kijbunchoo, Sumeet Kulkarni, Mike Landry, Sean Leavey, Susanne Milde, Brian O'Reilly, Sascha Rieger

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)

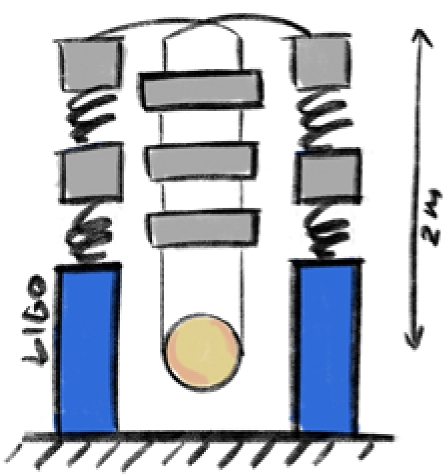
The LIGO Magazine is printed on certified sustainable paper.



Baffled LIGO scientists, two researchers at LIGO Hanford's Pre-Stabilized Laser enclosure baffled by the low amount of light coupling into the new fiber coupler they just installed, by Nutsinee Kijbunchoo. The photograph won the 2019 International Wiki Science Photo Competition, as well as the U.S. Joriy's choice award.

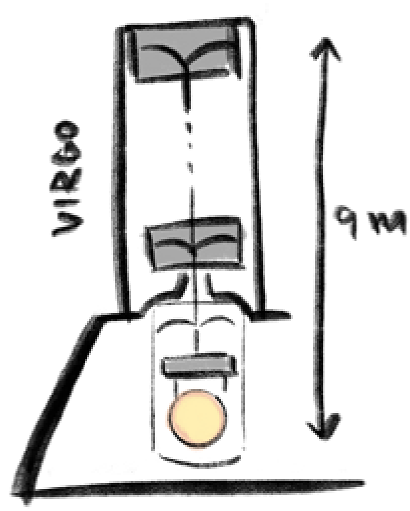
All gravitational wave detectors require seismic isolation to prevent ground motion from spoiling the extreme sensitivity demanded by such devices. Low frequency ground motion causes the earth's surface to shake on the order of a micron. To achieve a significant detection rate, gravitational wave detectors have to measure length variations that are at least 10 orders of magnitude smaller! Each observatory achieves this slightly differently; here we focus only on the isolation systems for the test mass mirrors.

Broadly speaking, isolation can be split up into two categories: active and passive techniques. Passive isolation is achieved by suspending the mirror using a series of connected pendulums and springs: the motion of the mirror is suppressed for vibrations faster than the mechanical resonance of the system. Active isolation then involves measuring a signal on the isolation stage and feeding it back to an actuator which drives the stage in the opposite direction with the same amplitude.



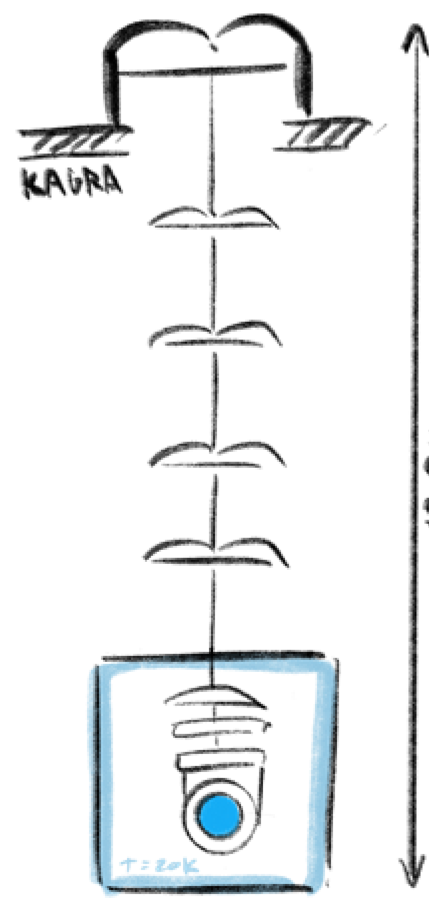
So, now the complicated bit is out of the way, how does each site do it?

Virgo is based on the ground. Its 'Super Attenuators' consist of 6 springs and 7 pendulums, hung from the top of a soft three-legged inverted pendulum. From the top to the penultimate stage, single wires are used between stages, while the mirror itself is suspended using glass fibres. This is a passive attenuation system.



Like Virgo, **LIGO** is ground-based. The test mass suspensions are attached to a two-stage isolated platform. This reduces the input ground motion seen by the test masses by a combination of passive and active control. Combined with this, LIGO uses passive isolation in the form of springs and a quadruple pendulum system ("QUAD"), with the bottom two stages monolithically suspended by glass fibers.

KAGRA is underground to reduce seismic noise by a factor of 100, and cryogenic to reduce thermal noise. The 'Type A' system, similar to the Virgo design, is suspended from the second floor of the cavern. The bottom four stages, including the sapphire test mass, are installed in a cryostat to cool the system down to just 20K (about -253°C). Significant effort is spent to avoid 'shorting' the isolation system via the heat link to the cryostat.



 by Sam Cooper, Ettore Majorana and Lucia Trozzo