LIGO Scientific Collaboration

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LIGO MAGAZINE

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Front cover

A photo of a kangaroo by GOTO, the Gravitational wave Optical Transient Observatory. GOTO is designed to quickly search large areas of sky for transients associated with gravitational-wave signals. Around the world and in space, electromagnetic facilities are following up the gravitational-wave candidates observed during the current Observing Run 4. Article on pp. 10-12.

Top inset: An example sky map for an Observing Run 4 gravitational-wave candidate. The example shown is for the candidate S230518h, which is discussed in the article on p. 9.

Bottom inset: Working on the GOTO Southern observatory in Siding Spring, New South Wales, Australia.
Article on pp. 10-12.

Bottom left (diagonal) inset: An artistic impression of a pulsar timing array. The Earth is shown in the middle of the image, surrounded by pulsars in our galaxy. Further out, supermassive black hole binaries produce a background of gravitational waves. Article on pp. 22-23.

Image credits

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Cover: Main image: Photo of kangaroo at GOTO by Ben Godson. Top inset: Sky localization from the LIGO-Virgo-KAGRA Collaborations. The plot is from GraceDB (https://gracedb.ligo.org/superevents/S230518h/view/). It is a Mollweide projection of Bilby.multiorder.fits, submitted by LIGO/Virgo EM Follow-Up on May 18, 2023 15:33:32 UTC. Bottom inset: Photo of working at GOTO by Kendall Ackley. Bottom-left (diagonal): Artistic impression of a pulsar timing array by Carl Knox / Swinburne / OzGrav.

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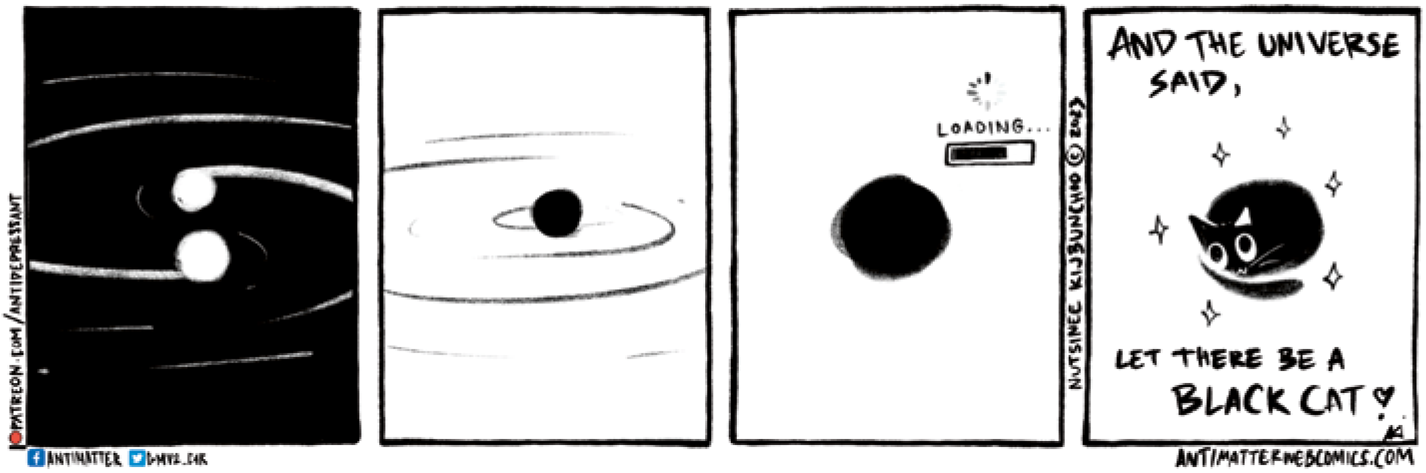


Welcome to the 23rd issue of the LIGO Magazine!

Hannah Middleton
Editor-in-Chief

Anna Green
Deputy Editor-in-Chief

Welcome to the twenty-third issue of the LIGO Magazine! Observing Run 4 (O4) has started and gravitational wave candidates are being detected every few days. In this edition we catch up with several of the activities around O4, from the preparations in "What happens before an observing run?", the journey of a gravitational wave candidate on the back cover, and a memorable experience of one particular candidate in "Rapid response to S230518h". Electromagnetic observatories have also been gearing up for O4 and hoping to capture light associated with gravitational wave events – GOTO team members Kendall Ackley and Ben Godson recount a race against time in "Tales from the Cosmos".

This September is the first time a LIGO-Virgo-KAGRA meeting is being hosted in Japan, near the beautiful mountains where KAGRA resides. Takashi Uchiyama and Kazuhiro Yamamoto take us on a tour of Toyama and KAGRA in this issue. Speaking of conferences, how do you choose which ones to go to? Amanda Baylor and Jessica Steinlechner talk through a few things to consider in "Making the most of your conference travel".

Looking beyond ground-based detectors, the pulsar timing array consortia recently announced tantalising evidence of low-frequency gravitational waves. Alberto Vecchio tells us more from behind the scenes in "A new window is opening".

Looking to the future, there is good news for LIGO-India as the Indian Government has approved construction of a new detector in Aundha – find out more in "A green light for the LIGO-India Project". In this edition's "Meanwhile in Space", Sarah Paczkowski explains how tilting test masses can create noise in LISA and how to tackle it.

Also in this edition, we catch up with Sumeet Kulkarni on his time at the LA Times in "My experiences as a science reporter" and hear about the latest in the series of LIGO documentary features by Les Guthman in "Back in Production".

Finally we remember the life of Rhondale Tso, from his work on precision tests of general relativity to his community outreach. He will be missed.

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

Hannah Middleton and Anna Green, for the Editors

News from the spokespeople

We are pleased to announce that Jess McIver is the new Deputy Spokesperson of the LIGO Scientific Collaboration (LSC). She is responsible for onboarding new LSC groups and new senior members, running a mentoring program for Principal Investigators of LSC groups, running the annual review of LSC groups' past and planned contributions to the LSC, as well as joint duties.

We are well into the fourth observing run (O4) of LIGO-Virgo-KAGRA, and the excitement, challenges, and opportunities of gravitational-wave astronomy are on full display. The detectors at LIGO Hanford and LIGO Livingston transitioned from the engineering phase to the observing run on May 24, 2023. They were joined by KAGRA for the first month of O4. Unfortunately, Virgo experienced problems with excess noise in their detector that required repairing two mirrors suspended in vacuum; Virgo hopes to join O4 later this year. With the tremendous successes of the recent past, it is easy to underestimate the challenges of maintaining and enhancing our gravitational-wave detectors. They are complex instruments that use cutting-edge technology pushed to the limits. The detectors are the engines driving our observational science, and it is vital for us all to share experience, ideas, and time to improve all of the detectors.

We are currently detecting about one compact binary merger every three days using our low-latency search and alert pipelines. There are already hints of exciting new results. With the improved sensitivity, we may identify continuous-wave sources, a stochastic background, or some surprise source for the first time in O4. There is lots of work needed to prepare the data, search for the sources, and understand our results. We are grateful to everyone investing time in critical infrastructure and operations activities – you make our science possible. We encourage everyone to contribute to these activities that need more personpower. Enjoy contributing to the Collaboration papers that will come out of O4!

A very exciting development since the March LIGO-Virgo-KAGRA meeting is that the LIGO-India construction project has been approved with the goal of operating a new LIGO detector in Aundha in the Hingoli district of Maharashtra by 2030. The global gravitational-wave community is actively working toward building next-generation detectors, which would begin operating towards the middle to end of the 2030s. In a pair of white papers submitted to the National Science Foundation's subcommittee on the Next Generation Gravitational-Wave Observatory, a roadmap was presented for enhancing and operating the LIGO detector network, including LIGO-India, into the 2030s and dovetailing with next-generation facility operations. The vision for gravitational-wave astronomy over the next 20 years is compelling.

It is an exciting time for our field. Thank you all for contributing to the success of the LIGO Scientific Collaboration.

Patrick Brady
LSC Spokesperson

Jess McIver
LSC Deputy Spokesperson

What happens before an observing run?

▲ *The LIGO Livingston control room.*

It is curious to think about what happens at the gravitational-waves detector sites when these massive observatories are not quietly listening to the universe! After a successful observing run, we make several improvements to these detectors. Then how do we smoothly transition back to another observing run?

Some aspects of the calibration, data quality, and analysis pipeline require live and/or simultaneous data from the observatories for testing. This phase is termed an *engineering run*. During this run, the operational team will try to get the detectors running relatively free of configuration change. Accordingly, the commissioning team will make a few final adjustments to the detector's operating state and automation.*

The recent engineering run (ER15) took place in the lead up to the current Observing Run 4 (O4), which started on 24th May 2023. Now let us hear from people who were leading the show at LIGO Hanford in ER15 on what happened in and around the ER15 specific to their field.

From the perspective of ER15 Lead

First a recap on the last two years. We spent most of 2021 and some of 2022 making upgrades to various parts of the LIGO-Hanford (H1) and LIGO-Livingston (L1) detectors subsystems, working inside of many detector chambers installing upgrades for stray light control, new dampers, new HAM6 optical layouts with improved suspension controls, new Test Mass optics with less absorption, and a 300m long A+ Frequency-dependent filter cavity with two new suspended cavity optics (details in Sept 22 LIGO Magazine). An upgrade was also performed on the Pre-Stabilized Laser (PSL) table to add another stage of amplification to the input laser system (details in March 23 LIGO Magazine). We then made jumps between shorter activity upgrades and commissioning periods dur-

Betsy Weaver

is the LHO Detector Group Lead and spends most of her time planning detector upgrades and repairs. Her recent hobbies are camping, hanging out at the folks' floating river home in Portland, and following the HS Junior around to volleyball games. She is shipping a kid off to college this fall (Go Cougs!) but isn't ready to accept it.

* *taken from LIGO-G2300834*

by Betsy Weaver, Keita Kawabe & Jeff Kissel

ing the second half of 2022, eventually commissioning the detectors with higher power and seeing ~20-30 Mpc range increase from Observing Run 3 (O3). By the end of ER15, H1 was logging a binary neutron star Inspiral Range (IR) of ~130 Mpc, and L1 IR of ~150 Mpc. (Note, H1 Range has increased to 145 Mpc since the beginning of the O4 run due to continued adjustments on the detector to bring it inline with L1. A few hours are allocated each week during O4 for commissioning work to continue improving H1 and L1 range and duty cycle.)

This recap is to point out that during most of the last few years, detector staff effort was focused on cranking up the duty cycle and sensitivity range of the detector which required a dynamic running condition, full of a barrage of measurements, fixes, and adjustments. However, to actually be ready for an observing run, a few system shake downs required a more stable, untouched interferometer running condition. Time was allocated at both sites to work on each of these systems during the ER15 transition period. As is typical for many of our prior engineering runs, these systems are in the areas of interferometer configuration control, calibration, data pipeline event testing, launching of the Rapid Response Team event protocols, some physical-environmental baseline measurement sweeps, and setting up the logistics of staff backups for any anticipated failure modes during O4. Careful coordination of all of these activities was needed in order to execute the full docket in the short one-month ER15, especially given the numerous interruptions from computer failures, power outages, and earthquakes, which caused unexpected down time for Hanford and Livingston. Even though everyone wished “we had more time”, we managed to complete enough work in time for O4! Of course, all of these preps were in complete collaboration with the O4 Run leads, Jenne Driggers and Brian O’Reilly, since we needed to make sure that all preps and system setups would bear the longevity of O4.

Responding rapidly!

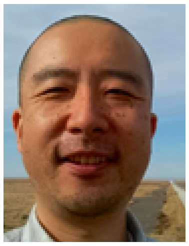
As soon as significant gravitational-wave candidates are found, we issue public alerts to let everybody know so the astronomers can find something in coincidence. After the first notice automatically goes out, the Rapid Response Team (RRT)* provides the human response to vet the event and tell the astronomers about the results. In O3, RRT was a small group of LIGO-Virgo experts. We had 80 public alerts in about a year, and the majority happened in the middle of the night for many, making this an extremely onerous service.

In preparation for O4, RRT membership was expanded significantly. Many non-experts from LIGO-Virgo-KAGRA, scattered across

* *See the back cover to find out more about O4 gravitational-wave alerts.*

Preparations for O4 at the LIGO sites

Keita Kawabe



is a senior scientist at LIGO Hanford Observatory. His expertise is in instrument science, but in recent years he has also been heavily involved in the operational side of the observing runs. In his spare time he enjoys playing guitars and photographing nature.

the globe, each take either 8 hour or 4 hour shifts in US, Europe, and Asia Pacific time zones to provide 24/7 coverage. With the help of automated tests and a step-by-step manual, they process the majority of candidates (mostly loud binary black holes) on their own, significantly reducing the workload of experts. The RRT group (chaired by Hisaaki Shinkai, Francesco Di Renzo, and myself) spent time writing and refining policies, manuals, rosters, presentations and training materials, as well as selecting and developing software tools.

ER15 served as a dress rehearsal for the RRT, enabling them to test everything under O4-like conditions. To my surprise, software, procedures and policies all worked almost immediately "out-of-the-box" except for minor hiccups here and there! We also used ER15 event candidates to train newly recruited responders. We provided "training days" with presentations and Mock Response sessions for all three time zones. Valuable feedback from responders helped to iron out issues further. And of course we had S230518, a likely neutron star – black hole candidate. RRT vetted it and sent out a human-edited public alert (read Francesco's article on page 9). Because of these ER15 experiences, we went into O4 with a confidence that RRT will work without much problem, which turned out to be true. We issued 9 public alerts (2 retracted) in the first month of O4 and RRT has been working smoothly so far!

Calibrating and progressing

One of the activities that Betsy mentions is the work of the calibration group. This group is responsible for delivering a real-time signal derived from the detectors' control systems that represents a model of the gravitational-wave strain measured by those detectors. The group also produces a modeled estimate of total systematic error and uncertainty, or a "systematic error budget" on that strain signal. The systematic error budget is informed by measurements and sub-models of the detectors' components that build up the controls. In the end, each model ends up being complex-valued, frequency-dependent, and changing slowly over time. This error budget is an integral part of understanding the uncertainty of the astrophysical interpretation of our signals.

Jeff Kissel

is the Control Systems Engineer for the LIGO Hanford Observatory (LHO). He celebrates his 20th year with LIGO and has served as a member of the LHO Detector Engineering team for 10 years. He's been honored to have been a part of the community since the detectors have increased their sensitivity from 15 to 150 Mpc!

In the past, such a model was crafted after two months of work understanding three-month data collection periods, or chunks, which have already happened. In those two-month periods after all three-month chunks of O3, the group carefully studied what actually happened to the detector calibration and created a well-informed, complete model of calibration error and systematic error [1,2]. However, this two month lag time in error budget availability was a leading delay in our ability to start the extensive computations required for astrophysical interpretation.

In order to keep up with modern astrophysical demands, the calibration group – for the first time – has worked on producing such a modeled systematic error budget in near-real-time. We aim to produce a systematic error budget concurrent with the data itself. That necessarily means we have a complete understanding of the detector calibration ahead of the incoming data and predict what the systematic error will be. This is done in the face of detectors, whose configurations and hardware are constantly changing. As such, we're also pioneering an independent, direct measurement of the systematic error.

The work on this monumental task did not begin in the engineering run. Instead, the stability of the detector during the engineering run allowed us to use this new schema to see if all of this hard work had worked. In the end, we were able to successfully demonstrate that we can deliver a calibrated data stream, as well as a measurement and model of the error budget of that data stream, and that the magnitude (and phase) of systematic error is thus far sufficiently low that it will not impact flagship astrophysical analyses.

Go team!

LIGO 2023

References

[1] Sun, Ling, et al. "Characterization of systematic error in Advanced LIGO calibration." Classical and Quantum Gravity 37.22 (2020): 225008.

[2] Sun, Ling, et. al "Characterization of systematic error in Advanced LIGO calibration in the second half of O3 (O3B)" LIGO Technical Note (2021): https://dcc.ligo.org/LIGO-P2100207/public

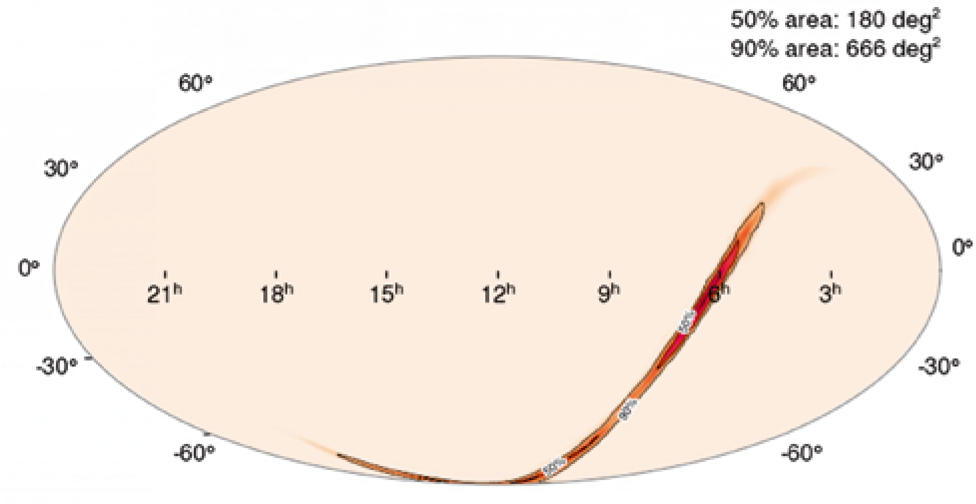
Rapid response to S230518h

by Francesco Di Renzo

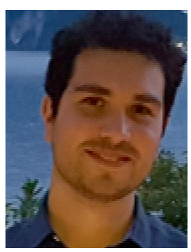
Contributing to the rapid response procedures for the compact binary merger candidate S230518h[*] has been an emotionally rich experience. This event marked not only the first case in the Engineering Run 15 (see p.6) phase preceding Observing Run 4 to receive full vetting and be released as public alerts to the astronomical partners – the first in three years! – but it is also a so-called "high-profile" event due to the nature of the compact objects involved.

The search pipelines that identified it (PyCBC Live, GstLAL, and MBTA) all agreed on classifying it as originating from the merger of a neutron star and a low-mass black hole. As of now, there have only been two confident observations of such a kind reported by the LIGO and Virgo collaborations [R. Abbott et al 2021 ApJL 915 L5]. Besides the challenge and exceptionality of the detection itself, these events provide significant opportunities for studying astronomical populations and formation channels, namely how stars and black holes form, as well as investigating the possibility of light coming from the merger which astronomers may be able to see (see p.10). This is why the automatic alert phone message of a similar candidate sparked great excitement in all the collaborations, with 200+ people joining the discussion on Mattermost and TeamSpeak where the rapid response procedure was in progress.

This was a personal challenge as well. Alongside the other coordinators of the Rapid Response Team, Keita Kawabe and Hisaaki Shinkai, we spent several months training our team how to carry out the vetting of similarly extraordinary events. We meticulously addressed all aspects related to conducting checks and validation procedures, and we strove to explain them in an organized manner. Specifically, we tackled all possible cases where any step of the rapid response pipeline could fail, and the people to contact.



The sky localization for binary merger candidate S230518h from gracedb.ligo.org. The candidate has been classified as a merger of a neutron star with a low-mass black hole. The plot shows a map of the whole sky, and the red/orange regions show the probable location of this candidate.



Francesco Di Renzo is a postdoctoral researcher at the Institut de Physique des 2 Infinis in Lyon, France, and a member of the Virgo Collaboration since 2016. He received the Virgo Award in 2022 for his contribution to detector characterization and noise hunting. In his free time, he enjoys playing and crafting.

It turned out to be that kind of situation, indeed. In some sense, this event happened too early as the fourth observing run had yet to start. A few things didn't work out as expected, or, to be precise, as would have been the expectation during the observing run. The preliminary notice was not sent out automatically, which triggered a few hiccups. Also, most of the pipelines were still uploading events on a test version of GraceDB, the website where information about potential gravitational waves is aggregated. The most stressful aspect certainly was that all the excited people trying to connect to GraceDB created an extreme load on the GraceDB server, and this dramatically slowed it down to the point of being practically unusable. It was my responsibility, as Level-0 responder, to browse through the superevent webpage, the webpage where information about the candidate from a variety of sources is displayed, perform the various checks and give signoff to this event, as well as prepare the circular to follow the public alert. The latter operations had been slowed down a bit due to the load on the server. Fortunately, the awesome team structure that we had contributed to building up performed surprisingly well, with all the experts in the various low-latency aspects giving their valuable support.

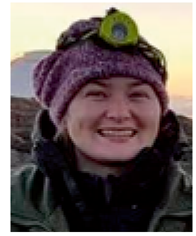
In this sense, it has certainly been a memorable experience for the whole LVK collaboration.

* *Keep up with the latest Observing Run 4 public alerts at gracedb.ligo.org and check out S230818h at https://gracedb.ligo.org/superevents/S230518h/view/.*

Tales from the Cosmos

The night sky above GOTO Southern Observatory, Siding Spring, New South Wales, Australia

Kendall Ackley



is a postdoctoral research fellow at the University of Warwick working on GOTO commissioning and operations, observational gravitational-wave astronomy, and multimessenger explosive transients. She enjoys the outdoors and foraging.

Ben Godson

is a first year PhD student at the University of Warwick who works on GOTO's operations and follow-up campaigns of young astronomical transients. Outside of research he enjoys practicing photography and videography.

With the start of Observing Run 4 (O4) looming, Kendall Ackley and Ben Godson, part of the dedicated team working with the GOTO Collaboration, embark on an extraordinary adventure across continents to install and fine-tune 32 cutting-edge telescopes. From the picturesque Canary Islands to the vast Australian landscapes, their journey is filled with challenges, close encounters with nature, and a race against time.

November 2022
La Palma, Canary Islands: Perfecting the Footprint

Our first destination on this voyage was the captivating island of La Palma, where the GOTO project's Northern observatory awaited us. We recently completed a full upgrade from the original prototype to the final system. After years of dedicated effort, fine-tuning the instruments, developing software and strategies for fully robotic control, and battling volcanoes and earthquakes, our final mission was to meticulously adjust the telescopes' footprint (the view the telescope has of the sky). This would maximize the field of view for following up gravitational-wave candidates. At this time, O4 was slated to begin March 2023, so the pressure was on to get the system in its final state.

Kendall: Well done Ben, that was quite the effort! After many long nights of standing on ladders until dawn, the results are looking great. We can increase our grid tile size by an additional 4 square degrees – almost the field of view of a single telescope.

Ben: We probably could've left it a few hours ago, but I'm glad we spent the last night getting it perfect. Fewer tiles means less time searching each gravitational-wave skymap. We should have a 20% reduction in the time required to tile a typical skymap.

Kendall: We split the effort and made quick work of it as a team. As I adjusted a telescope in declination (Dec), you adjusted the right ascension (RA). With rotations of bolts by fractions of a millimeter, it can quickly become tedious.

Ben: And with every RA/Dec change, we also needed to rotate the camera. Luckily the weather was on our side and everything fell naturally into place. Speaking of nature, I wonder how our crow friend is doing.

As if on cue, as we stepped out of one dome, our crow friend returned. The crow had been visiting us for the entire week, ever so curious as to what we were doing with our shining tools. We all had our own name for our inspirational mascot, but in the end we settled on Gerry the good GOTO crow.

Ben: In La Palma, we've had years to prepare. In Australia we only have a few months. Do you think we'll make it?

Kendall: That's a good question. Luckily with all the time we've spent preparing, we have a good sense of how our telescopes behave, how to install them, and how to collimate them quickly. It'll be tough work, but as long as they arrive on time, we can make it.

Ben: A lot of our experience so far has been on installation, preparation and fine tuning. We've had to wait on quite a few external events to line up. It feels like we're on the outside a lot of the time, waiting: waiting for the telescopes, waiting for the start of O4, waiting for good weather. It's a lot of uncertainty at each stage. We never know how long we'll be waiting.

March-April 2023
Australia: Racing Against Time

Kendall was first on site, arriving on a warm autumn evening. Ben joined a few weeks later at a pivotal time when the telescopes were turned on for the first time. The sprawling Australian landscape presented unique challenges. Under the relentless Sun, they toiled tirelessly, assembling and calibrating the Southern observatory, fueled by the urgency of the mission. The on-site shed provided refuge from the intense environment and coffee was endless in supply.

This time, instead of a crow, many other animals came to visit. A family of kangaroos was endlessly curious with the bustling activity.

Kendall: Leaving behind La Palma, we

GOTO is the Gravitational wave Optical Transient Observer. It is a robotic telescope that searches large areas of the sky for transient (short-duration) optical sources. The merging systems that produce gravitational waves can also produce electromagnetic light, especially if there is a neutron star involved in the merger. Around the world (and in space!), observatories at multiple frequencies follow up gravitational-wave alerts. Responding quickly is key to capturing the light from these events, enabling multimessenger astronomy with gravitational waves and electromagnetic light. GOTO is designed to rapidly search the sky for optical light associated with gravitational-wave candidate observations from the LIGO-Virgo-KAGRA network.

A family of kangaroos were endlessly curious about our activity at GOTO.

found ourselves in the vastness of Australia, where time became our greatest adversary. After months of delay for things outside of our control, we were feeling the pressure to prepare a full 16-telescope site with the clock quickly ticking for the new start of O4, May 2023.

Ben: New South Wales, where Siding Spring Observatory is located, was receiving record rain in the second half of 2022. Installing the concrete pads which our domes sit on would have to wait until the rainy season ended. In late 2022, the concrete pad and two domes were finally installed. Delays in shipping the final 8 telescopes and waiting for contractor work to finish kept pushing back our installation date.

Kendall: As soon as we heard it was all ready, we packed our bags and arrived on site on 26 March 2023. We gave ourselves a deadline of three weeks to complete the full 16-telescope observatory from the ground up with only a concrete pad and two domes when we arrived.

Ben: This strict deadline was necessary as once operational we needed to observe as many reference images of the sky as possible before O4. We can't identify any new sources in the sky without records of what is already there.

Kendall: With the help of a crane and many hands, we installed the mounts, the boom arms, and all 16 telescopes over the course of two days. Afterwards, we spent many days drawing power cables through underground conduits for the subsystems, wiring network cables from scratch, installing servers and the software to communicate with each telescope independently, and performing general maintenance. The silicone around the dome formed a leak and with rain on its way, repairing it became urgent. On the 31st March, we powered everything on and took our first image.

Ben: Working day and night under that pressure can be challenging, but there was also a real sense of camaraderie which developed in the team. Of course, first light is just the beginning; each telescope could take an entire night to collimate properly. And once the optics are aligned within each, they must all be aligned to the footprint.

Kendall: We're almost finished with the final details. I think we can be proud of what we've achieved all together. Once we're done with installation and we transition into our survey mode, there's still much to do. We'll be operating over nearly continuous 24 hour timeframes. There really isn't any down time. And to add to that, we don't know when the gravitational-wave events will come. Once they come in, it's going to be all hands on deck.

Ben: It can be tempting to stay up all night vetting templates and candidates. But if we do that every night and for every event, when *the event* comes in, we won't be at our best.

It was an excellent point. A considerable amount of time was spent discussing strategies for follow-up, how to prioritize follow-up of gravitational-wave candidates, and how to avoid burnout.

Kendall: Compared to our O3 follow-up with the GOTO-4 prototype, GOTO-32 is now operating on a completely new scale, increased by nearly a factor of 10. Things are almost ready for robotic mode as the infrastructure is all set up. We now need to finish the footprint and to install the robotic software. Then we're ready for O4. Oh, and by the way, there is a mouse in the shed.

Celebrating Success and Embracing the Future

The mouse ultimately set up its den where our fiber optic cables entered the shed and ate through them completely. For some time we were completely isolated from the external world. But it was here we took stock of what we completed together as a collaboration. We let ourselves take a brief moment to appreciate the quiet moment, contemplating the expected daily O4 events. Then we filled up on coffee and TimTams and continued on.

LIGO 2023

Gerry the good GOTO crow at the La Palma observatory.

Essential skills for Researchers

Gravitational-wave detectors and the main labs working as test-benches are built in places where quietness from human life can be assured. This is because a very stable environment is needed to be able to detect a gravitational-wave or to test advanced technology.

Example of a kit for first aid in case of snake bites. This is kept in the common room of the lab for people to use in case of emergency. Everyone is educated on how to use the kit properly while waiting for help from the in-charge person for this type of accident.

It happens then that the best spots are quite far from human living places – meaning that they are in the middle of nothing…

Most of the time, this "nothing" can be a dangerous place, and scientists must undergo a training program to be able to travel, work and live safely in that environment.

Chiara Di Fronzo

is a postdoc researcher in gravitational wave instrumentation in Belgium, and in 2019 she was an enthusiast wanderer of science-life at LIGO Hanford! When not science-doing, she sits on her yoga mat.

But why are these places potentially hazardous?

Well, because they are literally wild places of Nature…

Instrument sites are built in the natural home of many wild animals, in the respect of their original habitat, and it is then mandatory for whoever works on site to know how to behave in order to be safe. "This is scary!", said my mum once, but actually it just teaches people to co-live with the autochthon wildlife.

How does the training work? On site, there is always a team of experts who introduce the new arrivals to the procedures in case of a close encounter: depending on the environment, they provide specific instructions. The pics I collected on sites in LIGO Hanford (USA) and AIGO (Western Australia) give you an idea!

My experiences taught me what to do in case I hit a deer with the car in the US desert or if I'm bitten by a snake in the Australian bush. Petting the cute wild kangaroos that sometimes approach the AIGO site can be tempting, but I was warned that they are full of ticks: it's better to just enjoy their cuteness from afar :D

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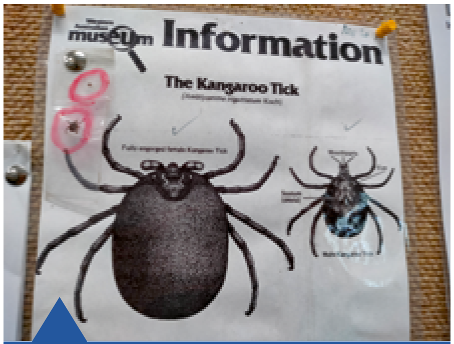

People working in labs built in the Australian bush are educated about suitable clothes to wear to avoid getting a kangaroo tick. You can get a tick via kangaroos or via trees. The trees are actually a more likely way to get one as kangaroos are shy and don't come close to you!

Meet Pete! This guy (or girl? never been sure…) was enjoying his time out of the window of our fellow apartment on LIGO Hanford site (USA). We decided to let it stay, keeping an eye when opening the windows and enjoying its amazing shape.

A green light for the LIGO-India Project!

A conceptual aerial view of the LIGO Aundha Observatory.

On the 6th of April 2023, the Government of India approved the LIGO-India Project – the construction of a new gravitational-wave observatory in Aundha, India which is scheduled for completion by the end of this decade.

Sendhil Raja

currently heads the Advanced Electro-Optics Section, at the Raja Ramanna Centre for Advanced Technology (RRCAT) which is responsible for the Detector part of the LIGO-India Project. In his spare time he enjoys water-color painting with his daughter.

LIGO-India is a Mega-Science Project under the Mega-Science Consortium of the Department of Atomic Energy (DAE) and the Department of Science and Technology (DST) of India. The DAE will build the observatory in collaboration with the LIGO Laboratory-Caltech and LIGO-Laboratory-MIT in the USA. LIGO Laboratory is funded by the National Science Foundation (NSF) of the USA. The project cost in rupees is estimated to be 2600 crore (approximately 300 million US dollars). LIGO-India will join the current international network of gravitational-wave detectors comprising LIGO-Hanford (LHO), LIGO-Livingston (LLO), Virgo and KAGRA. The LIGO Aundha Observatory (LAO) will be of the advanced LIGO configuration, like LHO and LLO. The LIGO and Virgo gravitational-wave detectors have opened up an entirely new window of observation into our Universe. With the improved source localisation that LIGO-India will provide, many important questions in fundamental physics will be answered, giving India an opportunity to contribute to world class science.

The LIGO-India Observatory will be set up under an international collaboration with LIGO Laboratory, Caltech and MIT. As part of the collaboration, LIGO-US will provide the complete design and the key components of the advanced LIGO detector to India. In India, the LIGO-India Project is led by the DAE Institutions; Raja Ramanna Center for Advanced Technology (RRCAT) Indore, Institute for Plasma Research (IPR) Gandhinagar, and the Directorate of Construction Services and Estate Management (DCSEM) Mumbai along with Inter-University Centre for Astronomy and Astrophysics (IUCAA) Pune, a University Grants Commission (UGC) institution. Apart from these lead institutes, a large number of researchers from various institutions across the country are part of the LIGO India Science Collaboration (LISC) and contribute to the project by way of pursuing activities related to various aspects of gravitational-wave detector and data science.

The road to LIGO-India

In the 1990s RRCAT and IUCAA proposed the development of a 100-meter arm length interferometric gravitational-wave detector prototype to develop expertise and detector components for a future kilometer-scale gravitational-wave detector. The proposal was not funded as it was felt that it was too ambitious and unrealistic at that time. In 1995 a collaborative effort between Australia and India (RRCAT+IUCAA) explored the possibility of building a 3-kilometer arm length interferometer for gravitational-wave detection near Perth, Australia. The plan was for the India team to participate at about 10% (in-kind) contribution and, with the expertise gained, pursue the development and construction of a kilometer-scale gravitational-wave detector in India. The collaboration was not able to secure the desired level of funding to go ahead with this proposal.

Then in 2009, the LIGO Laboratory was decommissioning the initial LIGO detectors in order to build advanced LIGO. Informal requests were made to LIGO-US to “loan” the components of initial LIGO to build a detector in India. In 2011, the NSF decided that better science could be derived from the LIGO project if three LIGO detectors separated by global distances were operational. It explored the idea of using one set of advanced LIGO components to build a LIGO detector far away from the two in the US. Various options were explored including Australia, Argentina and India. Since a location in India provided a large baseline between the detectors, the compelling scientific benefits of better source localisation motivated the LIGO Laboratory to explore the possibility of collaboratively building a LIGO detector there. In 2012 the NSF formally agreed to provide the components for one advanced LIGO detector in a collaborative project to build LIGO India. The proposal for LIGO-India was made by the Indian team to the DAE-DST Mega-Science Consortium. The Mega-Science Consortium agreed to pursue the LIGO-India Project with DAE taking the lead responsibility for the project.

A place for LIGO-India

LIGO-India will be located at Aundha, in the Hingoli District of Maharashtra, which was selected due to its very low seismic noise background. Among the various Mega-Science Projects currently being pursued by the Mega-Science Consortium of DAE and DST, LIGO-India will be the first Mega Science Project on Indian soil. This will enable a significantly larger number of Indian students and researchers to contribute to the emerging field of gravitational-wave astronomy and associated cutting-edge science and engineering without having to travel abroad. As a world class Mega-Science facility it is also likely to attract researchers from abroad. This will put Hingoli on the global map in the evolving scientific field of gravitational-wave astronomy, and has the potential for Hingoli to evolve into a Science City in the future. A science outreach centre called “Light & Gravity” is also being planned in Hingoli as part of the LIGO-India Project.

Subsequent to identification of the site at Aundha, Hingoli, the Government of India gave “in-principle” approval for the LIGO-India Project in February 2016 to proceed with pre-project activities such as site acquisition and preparation of a detailed project report for seeking financial sanction for the construction phase. Site acquisition, site characterisation, vacuum prototyping and setting up of a Testing and Training facility were completed as part of the pre-project activities* and financial sanction for the construction phase of the project was sought in December 2022. In April this year (2023) the Government of India approved the project for construction of LIGO-India.

I hope that the current engagement with LIGO-US will foster long term collaboration as part of the global network of gravitational-wave detectors, and lead to future contributions to the research and development efforts for the next generation of gravitational-wave detectors.

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Top: Internal view of the Testing and Training facility at RRCAT, Indore.

Below: The foundation stone laying ceremony plaque at the LIGO-India site.

* *See also articles in LIGO Magazine issues 19, 21 & 22*

Back in production

Film crew at Caltech in May 2023. Left-to-right: Director of Photography Beth Napoli, Sound Recordist Alejo Ramos-Ariansen, Director Les Guthman, Producer Christine Steele.

I am delighted to let you know that our 2019 feature documentary “LIGO” is now streaming for free on YouTube around the world. The link is https://youtu.be/dX4vCNi544w.

We began filming “LIGO” in August 2015 at Caltech, interviewing Norna Robertson, Kip Thorne, Barry Barish and Dave Reitze. Then I took the crew to Livingston for the launch of Advanced LIGO. We interviewed Gaby González on Sunday, September 13, 2015; and, reflecting what everyone else had told me, she said they didn’t expect to make a detection for another year, at a minimum.

“Because,” she said, “We don't think that we will have enough sensitivity to see events even if we wait for a year or so, until we get better.” But then she added with a big grin, “But we could! We could be lucky. There are some theories, that are very optimistic theories, that say we should be seeing coalescences of black holes. And who knows? They might be right!”

We walked into the Livingston Observatory the next morning* to film the 8:00 am meeting in the control room and we didn’t turn off our cameras for the next four days.

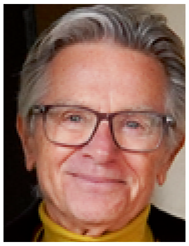
We continued filming well into 2017, as our National Science Foundation (NSF) grant called for a multi-part web series along the documentary. (That series, “A Discovery That Shook the World,” also resides on the same YouTube website.)

The film script was finished and we were beginning post production when GW170817 and its kilonova rocked LIGO’s world again and showed, as Jocelyn Read described to me so memorably a few months later, “We've said that the universe was kind to us with the first black hole merger being so bright. And then this neutron star merger days after Virgo turned on! The universe has been so kind to gravitational wave astronomy.”

We dropped everything and went to CERN for the LVC meeting a week later, where the air was electric with discovery — without the doubts and caution that colored that first week of GW150914 at Livingston. Then the Nobel Prizes were announced! The film script changed dramatically and our last shoot was an icy, magic December week in Stockholm with Rai, Kip and Barry, along with several dozen of their longtime LIGO friends and colleagues.

“LIGO” won 14 film festival awards, including two awards for Best Documentary. We received many good reviews. But those that meant the most to me were comments from the LIGO community, a few of which I would like to share.

Les Guthman



is an award-winning documentary director, writer, producer and editor. His longtime partner, the visual artist Susan Kleinberg, used the audio of the first two LIGO detections for her installation at the 2017 Venice Biennale.

* *The first detection of a gravitational wave signal was made that day, from the now famous binary black hole merger GW150914.*

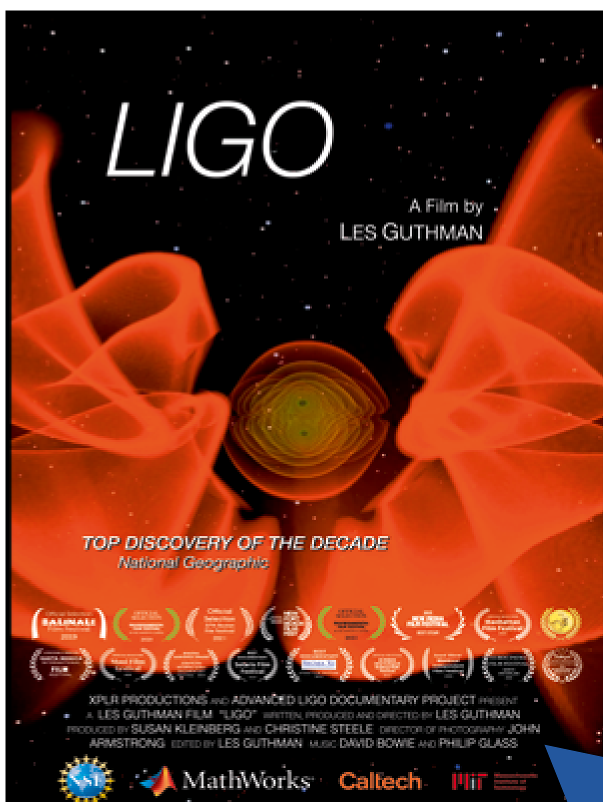
Nothing meant more than Rai Weiss' view of the film, "I don't think I have ever seen a better presentation of how science is done. You got all of it: the fundamental nature of the science, the joy of the people being part of the project, the excitement of the discovery but also the need for being cautious, the idea that this was the beginning of a new field of science."

I met Alessandra Buonanno at the Italian Embassy in Washington DC on the night of the GW150914 announcement at the National Press Club. I traveled to the Max Planck Institute for Gravitational Physics in Potsdam to film Alessandra and her wonderful group. She wrote to me, "What a special and unique movie! You really captured the way we embody our work, what science means to us and the many human facets of scientists. I found very faithful the way you have described the development of the events, and the seriousness and great enthusiasm with which we pursue our research."

Because we were funded in part by a grant from NSF, I was hoping they felt the grant was well spent. I received a lovely note from the director, France Córdova, whom Susan and I had gotten to know. I had also gotten to know Richard Isaacson, who had been the NSF Program Director for Gravitational Physics from 1973 to 2001. (See his article in LIGO Magazine Issue 6 3/2015). "I have never seen a better science documentary film," he wrote to us. "You captured the emotional side of a 'Big Science' project incredibly well. The role of individuals in this marching army emerged seamlessly, the hopes and fears that drive them to commit to a task of such immensity, complexity, and unending duration. You enable the film audience to experience the heroic human element in this adventure, and what motivates each player to devote a scientific lifetime to this single problem."

Finally, a lovely note from Rana Adhikari, commenting on one of our NSF video episodes, not on the documentary itself, but one that I hope would apply to the film as well, "Fantastic! I have to congratulate you on the look. There's something about the way that it's shot that really captures what the people are actually like in person. It's beautiful."

I also want to let you know that we are back in production, after a three-year COVID pause. MathWorks has generously underwritten a film I have wanted to make since I first met Norna Robertson, Gaby González, Janeen Romey, Nergis Mavalvala, France, Alessandra, Laura Cadonati and all the other impressive women I met in the early days of our filming in 2015-16. We are now in production on a new documentary featuring the women physicists and engineers of LIGO, a very special group, leaders and innovators all. They are all prominent in the first film, but I was further motivated to make the second film when many of the comments about "LIGO" singled out what my dear friend, the director Stavroula Toska, wrote me, "I really appreciate you highlighting all these female scientists and the work they've been doing. Their passion was electrifying!"



The LIGO film poster.

My experiences as a science reporter

Sumeet Kulkarni

is a Ph.D. student studying population properties of compact binary mergers at the University of Mississippi. He is an aspiring science writer and passionate about increasing public engagement in science. Sumeet pursues astrophotography in his spare time and when the night sky permits it.

"Hi, this is Bill Nye!"

Came the unmistakable, iconic voice through the other end of the line. I double-checked my call recording app and my backup handheld recorder, took a deep breath, and proceeded with the interview that was surely going to breeze past my memory straight into the closet of things too good to be true.

In the next 20 minutes or so, I asked the Science Guy about NASA's Voyager spacecraft and their scientific and cultural impact on humanity. He was friendly and it ended up being a nice conversation. I got the quotes I wanted, and thought I controlled my nerves well—until later that night when my iphone health app buzzed: "Your heart-rate rose above 120 BPM while you seemed to be inactive for 10 minutes starting 4 pm…"

I got a chance to do all of this because for ten weeks last summer, I was a science reporter at the Los Angeles Times as a part of the American Association of Advancement of Science (AAAS)'s Mass Media Fellowship. This program places STEM graduate students from North America in media outlets across the U.S. to undergo training in science journalism over a ten-week period with various media outlets across the country.

Within a week, I was thrust into the world of science journalism, digging into press releases, pitching story ideas, setting up interviews with the study authors and independent researchers, navigating embargoes (wherein results are made known to mediapersons in advance of publication) and crafting the pieces within quick turnaround times. One of the first press releases I encountered after signing up for a vast array of news services was the inauguration at the LIGO Exploration Center (LExC) at Hanford. Sadly, it was off-limits for me to write on due to conflict of interest.

Moreover, I wanted to write about science I wasn't very familiar with. My first story dealt with possible developmental disorders seen in newborns whose mothers were infected with COVID-19 during pregnancy. I had never written about medicine before, but familiarity with statistics helped me identify the most important outcomes of the study while leaving out more technical nitty-gritty. Interviewing experts helped me pin down the broader impacts of the study. Within three days, the story was out in the paper! Quite the gust of fresh air compared to my research manuscripts.

Over the next few weeks, I got to view a variety of vistas in the summer sciencescape. I reported on the discovery of the world's largest bacteria, profiled a pioneer of the semiconductor revolution, wrote about the ill-effects of California wildfire smoke on household cats, and saw tiny robots jump straight out of a 3D printer in a UCLA lab. In a multimedia feature piece, I highlighted the adverse effects of light pollution in the city by shooting timelapse videos that had progressively higher exposure times in each frame: the video got whitewashed in downtown Los Angeles, while showing the milky way band in all its glory from Joshua Tree national park just a couple of hours' drive away.

But the story I was undoubtedly most excited about was the release of the first James Webb Space Telescope (JWST) images. The first image was not embargoed: everyone would see it for the first time together! We thus had to prepare versions of the story with what it could be representing, and frantically edited it as the SMACS 0723 galaxy cluster field filled with countless galaxies was unveiled in the White House. The next day when the rest of the images were released was a bit more relaxed. I attended the press event at the NASA Jet Propulsion Lab (JPL) as the only print journalist among teams of broadcast folks. After doing a series of quickfire live interviews in front of big lights and cameras (which was a joy to watch), the JPL scientists told me how massively relieved they felt to sit down with me and my small handheld recorder.

While JWST dominated newspages and websites that week, I wanted to add a new angle to its reporting. I decided to give the big platform I had to early-career researchers and other graduate students who were leading efforts in the first observing cycles with this new $10 billion instrument. What was their reaction when their proposals got selected? What science are they most excited to uncover? This story highlighted fresh new faces in a new era of astronomy, and turned out to be a very memorable one to write.

Bringing science to the front page had been an initial goal of mine, and the first JWST image proved to be a home run. But to my surprise, three other stories of mine made it to A1! The first was the light pollution piece, which talked about how the proliferation of LED lights turned an apparent win for saving energy into a different environmental nightmare. The second was a fun feature where I interviewed researchers from six different fields, all using sound in various ways to either analyze their data, make it more accessible, or create music out of it.

Finally, there was the Voyager story. It started with a press release outlining some glitches in Voyager 2's health data relayed back to Earth. We decided to latch onto this to cover the bigger story about the challenges in keeping these relics of humanity going deep into outer space, all the while catching their faintest whispers for as long as possible. My editor said we needed a well-known voice to talk about just what these missions mean to science in general. I saw Bill Nye was the CEO of the Pasadena-based Planetary Society, so I emailed their office seeking an interview, not expecting much to come out of it. To my surprise, his secretary replied that he was free to talk for 20 minutes the following afternoon.

The next 24 hours were quite the blur. I was nervously looking over my list of questions and possible segues for the n-th time when the phone rang. It was Nye's secretary, who immediately put me to rest, chatting about my story, giving a brief outline, and granting permission to record. A couple of minutes later, he said he could now put the call through.

"I'm ready," I said, and heard the sound of a phone being picked up.

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How to get into science writing

- Start out by writing for the LIGO Magazine! Pitch us a story covering your research, or pen your thoughts on any aspects of life as a member of the collaboration.

- Write for your college or university magazine. In particular, pitch them everytime LIGO-Virgo-KAGRA release a collaboration paper – they will be more than happy to feature global research being done at home!

- It is not always easy to start or commit to your own blog; but there exist many graduate-student-run blogs that you can join to practice writing regularly! Examples include astrobites.org and the sciencebites.org network (worldwide), cosmicvarta.in (India).

- Some outlets such as theconversation.com exclusively invite practicing researchers to write about their field(s) – they have a team of editors to guide you through the process.

- Once you have a few clips from the above channels, you may apply for dedicated internships or even pitch your local media outlets.

Remembering Dr. Rhondale Tso

Dr. Rhondale Tso.

Our dear friend and colleague Dr. Rhondale Tso was laid to rest this past August. He was 34 years old and suffered from a lifelong heart condition. Rhondale, known to many as Ron, was a passionate scientist, cyclist, and traveler who pushed the bounds of our understanding of gravity and supported junior scientists around him.

Ron and I met as fellow PhD students working in the LSC, and we formed a friendship over many years as we attended workshops and conferences across the world together. I loved Ron's penchant for living in the moment, constantly learning new things, and bringing an open and supportive attitude to those around him. We enjoyed some incredible memories and experiences together, biking miles and miles in Copenhagen, squashing bugs in our codes in our summer office in Santa Barbara, going punting on the River Cam in Cambridge, and playing billiards late into the night in Chicago. We shared numerous friends and colleagues, and in the wake of Ron's passing, I had the chance to catch up with many of them and hear more about Ron's journey and his service to the community.

Ron undertook his undergraduate studies at Embry Riddle Aeronautical University, where he attained a BS in Space Physics. But physics wasn't the only thing that occupied him. After Embry Riddle, Ron went off the beaten path and spent a summer following a love for dinosaurs by working on an archaeological dig in Montana. He then returned to physics at Columbia University, studying "aspects of black holes that convert the darkest phenomena in the universe into the brightest beacons in the universe" with Dr. Janna Levin. Dr. Levin described Ron's work as "precise and mathematical and elegant." Ron continued his studies as a PhD student at Caltech with advisor Dr. Yanbei Chen. Dr. Chen told me that "Ron's main interest was to make precision tests of the predictions of general relativity, with the hope of finding hints about how general relativity and quantum mechanics might be reconciled, and to use gravitational-wave observations to reveal the nature of dark matter and dark energy." To do this, Ron specifically examined problems related to black hole spectroscopy, polarization tests, and graviton mass measurements, which were detailed in this PhD thesis entitled *Fundamental Ways to Probe Gravitational Waves Across Its Spectrum and Propagation*. Dr. Alan Weinstein, who was on Ron's thesis committee said, "He had a unique background and valuable perspective on STEM education. He was always a pleasure to talk to, learn from, and work with." Another of Ron's collaborators, Dr. Daniel Holz, said, "Ron was such a warm, easy-going presence. He was so creative, and was always thinking about new avenues and directions. And he was a great collaborator, supportive and perceptive. I will miss him."

Beyond Ron's research program, he was also heavily involved in community outreach, to which he proudly brought his Navajo heritage. He participated in multiple outreach events for high-schoolers on the Navajo Nation and Yakama Reservation, and in 2019 was awarded an APS Mini-Grant to translate LSC materials into the Navajo language. Ron also supported his department's Physics Bridge Program, Astronomy on Tap series, and other outreach events. A fellow LSC member and Indigenous physicist Corey Gray commented, "[Ron] was the first Indigenous person (other than me) I ever heard about who was in the LSC back in 2015, and I can't overstate the importance of this. For Indigenous physicists, it's a major loss to lose someone like Ron in so many ways—he was a vital role model, inspiration to youth, and a friend." Ron's impact on the public and on junior scientists was wide-reaching. Dr. Chen said "Ron cared about younger students and inspired them. Back at Embry-Riddle Aeronautical University, Ron is a legend. Even long after Ron left, when I met students from ERAU at Collaboration Meetings, they would talk about him proudly. Ron was also friendly to new students; he was responsible for convincing some of my current graduate students to join my research group."

Ron's support of students continued when he began as an NSF Ascend Fellow at University of Illinois Urbana-Champaign in 2022 under Dr. Nicolas Yunes. "Ron's perseverance and determination has inspired many and will continue to do so in the years to come," said Dr. Yunes, "He will be sorely missed." Rohit Chandramouli, a student in Dr. Yunes' group, also recalled his time with Ron. "We started discussing hierarchical triples as GW sources and Ron had a lot of interesting ideas for projects to do," said Rohit, "Since there were a couple others interested in hierarchical triples, Ron would meet with all of us and we had some great discussions together. Ron had a lasting impact on me, which speaks to his character, and I will cherish the fun chats we have had."

While it is hard to lose a friend, collaborator, and leader like Ron, I am reminded of our shared love of unraveling the mysteries of the universe and the unique moments we spent together. Like two merging black holes, our dance has come to an end, but the imprints of our friendship will be felt through gravitational waves, spilling out into the cosmos.

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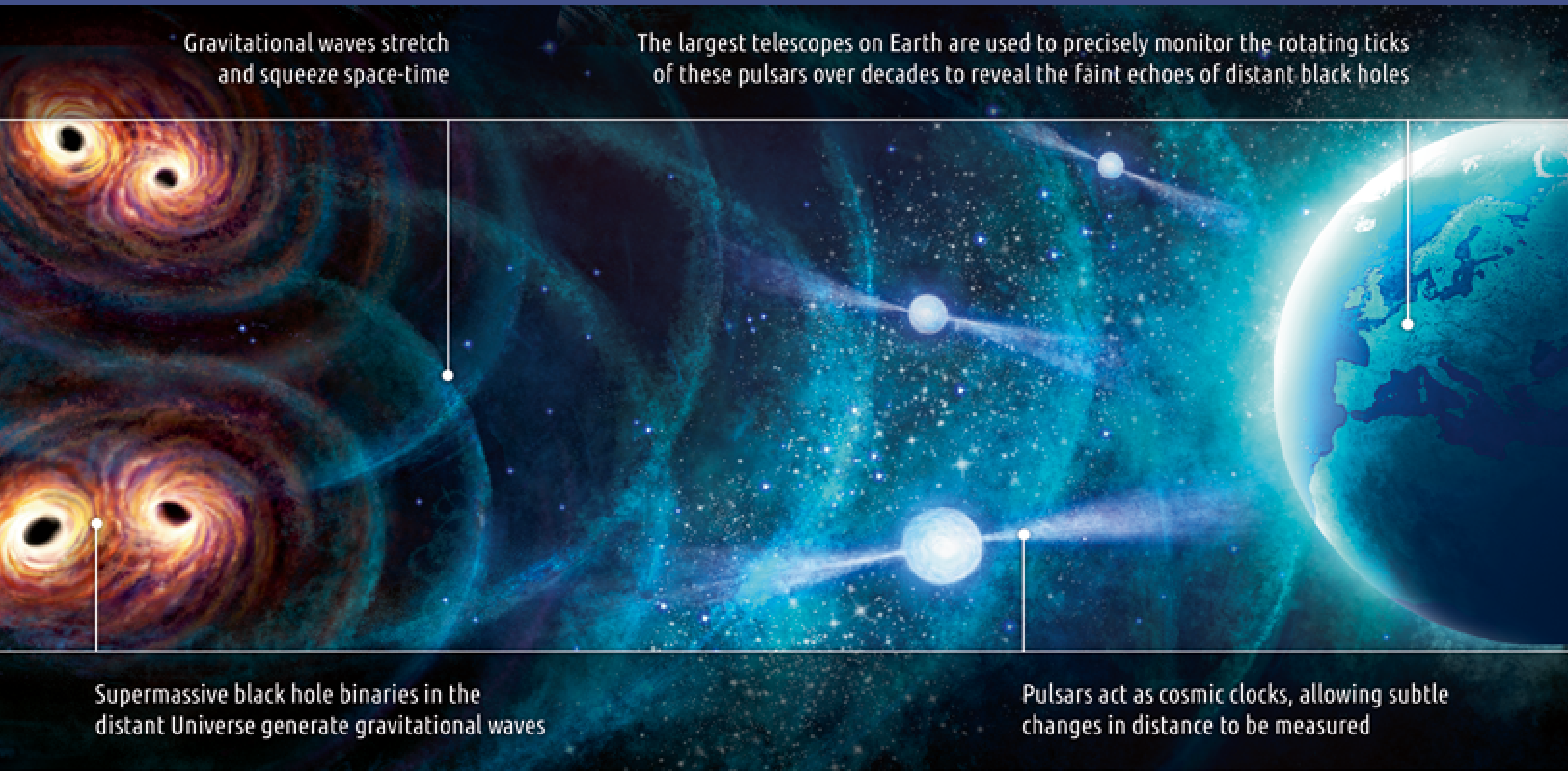
Pulsar Timing Arrays find evidence of GWs



▲ *The principle of Pulsar Timing Array gravitational wave observation.*

A new window is opening

"Colleagues, some of you may already know about this. I just learned an hour ago that the CPTA [Chinese Pulsar Timing Array] is on the verge of submitting a paper trying to claim evidence for GWs [gravitational waves]. We all need to have a conversation about this immediately, within the next 24 hours. I can be available any time, day or night."

The panicky email arrived very late at night, as I was about to close the laptop and go to bed. The commitment to science was admirable – "I can be available any time, day or night" – but surely it could wait until at least the next morning, couldn't it? My mistake was to hesitate for just a split of a second. Too late: a new email, a link, and we got on Zoom.

Alberto Vecchio

is professor of Astrophysics at the University of Birmingham, UK. He wishes to still be able to run a marathon.

Once upon a time, there was a plan. It was not perfect, but it was still a reasonable plan. According to the people involved, the negotiations spanned years, tensions ran high, the representatives left (and came back to) the negotiating table many times (sadly, this sounds all too familiar to those of us living in Britain). At the end, the "3P+ agreement" was signed. The

Further reading:

The key results of the PTA searches for a gravitational wave stochastic background can be found at:

- Chinese PTA (CPTA): https://arxiv.org/abs/2306.16216
- European PTA and Indian PTA (EPTA+InPTA): https://arxiv.org/abs/2306.16214
- North American Nanohertz Observatory for Gravitational Waves (NANOGrav) https://arxiv.org/abs/2306.16213
- Parkes PTA (PPTA) https://arxiv.org/abs/2306.16215

main pulsar timing array (PTA) collaborations – the Australian (PPTA), European (EPTA), Indian (InPTA) and North-American (NANOGrav) collaborations – had agreed to coordinate the release of their latest results and papers concerning their search for gravitational waves at ultra-low (nano-Hz) frequencies. Under the umbrella of the International PTA, this whole process would see preliminary results and information shared internally to enable some cross-checks and validation.

Work began in earnest when we were all still locked up in our homes dealing with much more serious and tragic global problems. By Easter this year, we were frantically crunching the numbers – "we have to re-run, the results have not been produced with the reviewed settings", was an all too familiar cry of desperation at teleconferences (if you work in "Parameter Estimation", you know exactly what I'm talking about) – when CTPA entered the scene. Those in the know assured us that several VIPs in the "3P+ agreement" could not believe their luck: there was finally a reason to throw caution to the wind and fast track the release of the papers. Gallons of coffee got drunk over a couple of weeks of non-stop zoom meetings and phone calls (having people in pretty much every time-zone in the world doesn't quite help to maintain a healthy work-life balance). Finally, a new agreement was reached: on June 29th CPTA, EPTA/InPTA, NANOGrav and PPTA would release their latest results of years of work to search for gravitational waves with pulsar timing arrays.

A pulsar timing array is a conceptually beautiful experiment. The recipe for such an experiment – or, in more modern and catchier language: a galactic-scale gravitational-wave detector – emerged between the late Seventies and early Nineties thanks to the pioneering work by Sazhin, Detweiler, Hellings, Downs, Foster and Backer. The key idea is to use milli-second pulsars as "clocks", thanks to their exquisite rotational stability. At every rotation, they send a sharp pulse of radio waves to Earth. As the radio signals travel through space and time, the presence of gravitational waves affects their path in a characteristic way: some pulses arrive a little (by a millionth of a second or thereabout) later, some a little earlier. The difference between the expected (with no gravitational waves) and recorded arrival time of these pulses carries information about gravitational radiation. This is an elegant, and relatively cheap way of exploring the nano-Hz gravitational-wave spectrum. The (big) problem is that many other effects, such as fluctuations in the interstellar medium, just to name one, also alter the regularity of the arrival time of radio pulses. The use of a collection of pulsars (an array) is the line of defence against this. Furthermore, as pointed out by Hellings and Downs in 1983, an isotropic gravitational wave background leaves a "smoking gun" signature in the correlations of the timing residuals from pulsars at different angular separation in the sky: the so-far elusive Hellings and Downs curve.

Artistic impression of a pulsar timing array. The Earth is shown in the middle of the image, surrounded by pulsars in our galaxy. Further out, supermassive black hole binaries produce a background of gravitational waves.

Pulsar timing arrays had been used to search for nHz gravitational waves since the end of the last millennium. Only upper-limits had been reported until now. The fuss about the papers released on June 29th is that, for the first time, some tantalising evidence of the Hellings and Downs correlation has been reported. The statistical significance of the results of the various analyses differs quite a bit depending on the data set: between about 2 sigma and 4.5 sigma. Indeed, I personally think quite some work is still needed to drill down into the details. Right now, the plan is to combine the existing data within the International Pulsar Timing Array and do an even more sensitive search, with larger discriminating power.

In the glamorous business of "opening windows" – I admit, "onto the Universe" carries a bit more allure than opening a window in a dingy flat – these results are quite exciting. If the evidence for a gravitational wave background grows, then we can start using PTAs to understand what is producing this signal, either the cosmic population of supermassive binary black holes or processes in the early Universe. Or perhaps we have just picked up, with a sub-optimal search, the signal from a lonely, not too distant supermassive black hole binary. New radio facilities will improve the PTA sensitivity. MeerKAT timing data are already exquisite, and the Square Kilometre Array is not too far off, so surprises may just be around the corner. Let's just hope that PTAs slam this new widow wide open, and a gust of dust doesn't shut it.

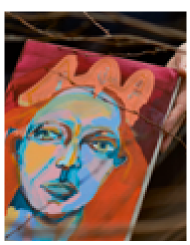
The Binary Coalescence Project

'Continuum' was selected for the Quantum Shorts Film Festival in Singapore in 2023.

The 'Binary Coalescence Project' is a unique collaboration, led by Aiv Puglielli, between astrophysicist Dr Linqing Wen and the StoryBursts program created by Claire Bowen and Kevin Vinsen.

The project comprises three audio visual films representing the artist's intuitive and creative response to Aiv Puglielli's interview with astrophysicist Dr Linqing Wen. The interview discussed Linqing's work on detecting gravitational waves from coalescing binaries comprised of black holes and neutron stars far away in the universe.

Claire Bowen



is an historian, playwright and executive producer, specialising in award-winning digitally captured creative nonfiction. She enjoys collecting antique furniture and avian pop art, and she can discuss the presence of fascist ideology in sci-fi fantasy literature underwater, if required.

The artists from all over the world who collaborated on the Binary Coalescence Project were all drawn to the project for different reasons – the cutting edge musical exploration, the challenging digital artwork, the synthesising of the natural world around us with the observations from the universe. They were all excited to be adding their artistic interpretations to a field that was so new; there is a particular thrill to being one of the artists who engaged with gravitational waves in its first decade of discovery.

All the artists acknowledged that Carl Knox's work[1] had really allowed them to expand their ideas of what is possible when it comes to responding to the gravitational-wave discoveries and that this work sits alongside Carl's oeuvre. The artists found it an honour to be creating images and music from the work of so many scientists working together across such a huge project.

Each artist was given free reign to bring their own unique talents to each piece, and reveled in the support from Linqing, and the absolute enthusiasm and involvement from her – it's not every day that an astrophysicist of her calibre will be in a music video for you!

Art and science has a common goal of deriving understanding which is explored through collaborations such as this as reflected on by Linqing, "[scientists] try to explain [concepts] but I think artists do it in a better way because they are connected, they reflect and understand the feelings of our community." Linqing remarked on the endless collaborative possibilities presented by gravitational waves as "the sounds come from the detection but the process of the merger can be a dance, a painting, and all sorts of artistic forms because it is so mystic".

This is a difficult project to summarise – it is a galaxy of ideas, skills, artists and audiences – and we find it means something different to each person that encounters it. At every point we have had the unwavering kindness of Linqing Wen and OzGrav helping us when we needed it. It's

[1] *see p. 23 and the front cover for some of Carl's artwork.*

been a dream come true to work with scientists and administrators who treasure art and artists so much.

Olivia Lee

is a freelance writer-turned-communications executive now working for the University of Cambridge's research centre based in Singapore. She enjoys diving, digital drawing, and looking at pictures of British Shorthairs which she hopes to acquire one day.

Space+Time

'Space+Time' incorporates voice and two pianos, as well as responsive visual artistry captured in the digital recording process. The human voice directly evokes a sense of reaction to the world around us.

Use of two pianos specifically provides capability for textural counterpoint, call and response between chordal instruments and polyrhythms across vast note ranges - altogether providing maximised vocabulary for the nonverbal communication of detailed scientific ideas. Recorded in the exquisite Melbourne Recital Centre with performers Aiv Puglielli, Pat Jaffe and Miro Lauritz, the digital capture of the performance has enjoyed great success in international film festivals: SCINEMA International Science Film Festival, Munich Music Video Awards, International Sound Music Video Awards (Prague), Manchester Lift-Off Film Festival (UK) and Scene Awards (USA).

'Space+Time' on the OzGrav YouTube channel: https://youtu.be/qPkB4HLix2s

Continuum

In 'Continuum', Singapore-based Malaysian artist Cheryl Chitty Tan performed several spoken-word interpretations of verbatim material captured from Dr Wen, while Berlin-based Singaporean sound artist Germaine Png utilised audio files based on real-world detections of gravitational waves to create a series of electronic shapes and melodic elements for the track. The visual element of 'Continuum' was created as a first response to the track by Perth and Sydney-based artist Rina Freiberg, and OzGrav's own Carl Knox created the time-lapse of Rina's work. In 2023 'Continuum' was selected for the Quantum Shorts Film Festival in Singapore, an initiative of the Centre for Quantum Technologies (CQT) and 'Continuum' was screened around the world, including at the ArtScience Museum in Singapore, in Ontario for the Institute for Quantum Computing, University of Waterloo and Dunedin for the Dodd-Walls Centre for Photonic and Quantum Technologies.

'Continuum' on the Quantum Shorts website: https://shorts.quantumlah.org/entry/continuum

P O N D

The music video 'P O N D' was inspired directly by a masterful aural painting of the irresistible attraction between two celestial bodies. 'P O N D' theorizes gravitational waves as human interactions on a horizontal axis, particularly of an intimate nature, and the external effect that can be perceived from an individual unit on its external environment. The music integrates floating articulations of the human voice and manipulated brass valves, set over a flowing synthetic compound. The music video imagines two neutron stars as individuals existing in isolation, with an open potential to be found, and was directed by Jennifer 'JP' Piper with Dasha Melnik as Director of Photography. Dr Wen joined the team at the exquisite Lake Clifton Thrombolites and played one of the two neutron stars. 'P O N D' has been selected for its first film festival of 2023, in Bali.

'P O N D' music video on YouTube: https://youtu.be/-ewluThhCTs

'Binary Coalescence Project' on Bandcamp: https://aivpuglielli.bandcamp.com/album/binary-coalescence-project

Frockup article exploring the music in detail: https://www.frockup.com/post/the-binary-coalescence-project-when-art-meets-astrophysics

LIGO 2023

Meet the artists

Aiv Puglielli: https://traktorbeam.org/
Jennifer 'JP' Piper: https://jenniferpiper.com/
Alexandra Nel: https://www.alexandranel.com/
Germaine Png: https://germainepng.com/
Cheryl Chitty Tan:https://www.imdb.com/name/nm6515471/
Rina Freiberg: https://www.rinafreiberg.com/
Pat Jaffe: https://patjaffe.com/
Miro Lauritz: https://linktr.ee/miromiro
Dasha Melnick: https://www.dashamelnik.com/cinematography
Claire Bowen and Kevin Vinsen: https://www.sciencewritenow.com/podcasts-and-interviews/ep-21-bursting-with-science-and-story
Melbourne Recital Centre: https://www.melbournerecital.com.au/venues/salon/
Lake Clifton Thrombolites: https://exploreparks.dbca.wa.gov.au/site/lake-clifton-thrombolites

Space+Time with performers Aiv Puglielli, Pat Jaffe and Miro Lauritz.

Linqing Wen in the P O N D music video.

Tilt-to-length noise in LISA

by Sarah Paczkowski

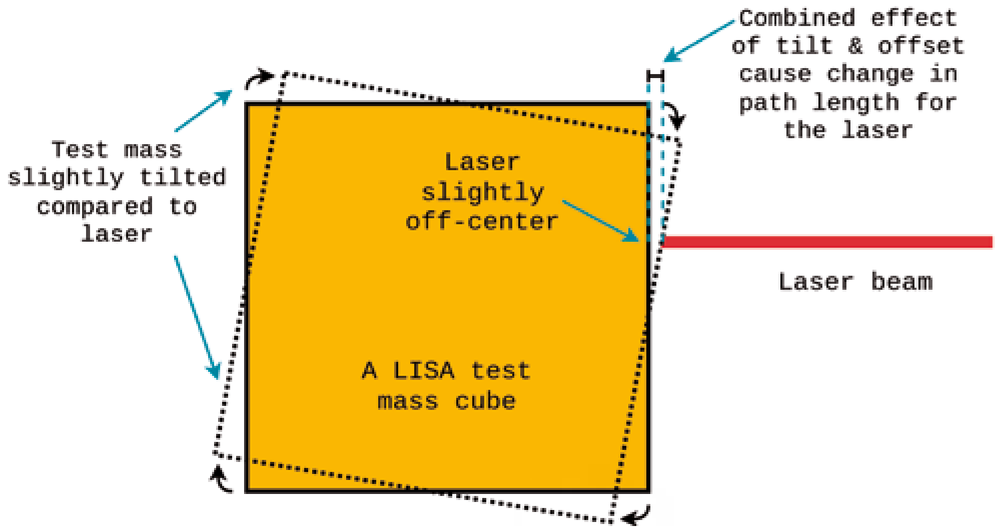
The Laser Interferometer Space Antenna (LISA) is a European Space Agency (ESA) mission with contributions from NASA. It aims to observe gravitational waves in the frequency range above pulsar timing arrays and below ground-based detectors: from 0.1 millihertz to 1 Hertz. LISA will observe a rich population of sources including massive black hole binaries and white dwarf binaries.

LISA consists of three satellites in a triangle configuration with 2.5 million kilometers between them. Like in ground-based detectors, laser interferometers will measure distance changes. But instead of end mirrors in the detector arms, LISA will have two free-falling golden cubes on board each satellite. These cubes are the test masses and will, ideally, be subject to no other force than gravity. To enable the planned LISA science, the interferometers must measure distance changes between the test masses in each of the three LISA satellites with an accuracy of around ten picometers at frequencies down to millihertz.

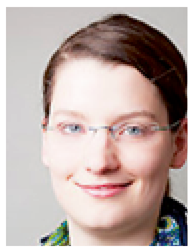
In LISA, several undesired noise effects need to be overcome to reach this interferometric measurement goal. The most significant disturbance will be due to small changes in the frequencies of the lasers. According to our current estimates, tilt-to-length coupling (TTL) will be another significant effect.

But what is TTL, and how does it arise? For simplicity, let's look at a single test mass (see picture). After even the most careful construction of the optics, the laser beam might hit one of the test masses slightly off-center, as shown in the picture. Also, a slight angular tilt cannot be avoided entirely. This leads to a measured change in optical path length which was not caused by gravitational waves. In general, the term TTL summarizes such effects on the laser optical path lengths and effects related to the measurement of laser beams [6]. By the way, there is a somewhat similar effect also in ground-based detectors called alignment control noise [1].

The currently expected noise from TTL will limit our distance change measurement accuracy, but will it cause a problem for LISA observations? We recently investigated if we can deal with this noise source in post-processing after the distance measurements have been made [2]. Our results are good news and indicate that it is possible to estimate the effect of TTL coupling and subtract it from the data in post-processing. This is the part of TTL in LISA where I'm involved. Studying different aspects of TTL is an area of active research for many LISA Consortium scientists – take a look at the references for more information.



▲ *What is tilt-to-length noise in LISA?*



Sarah Paczkowski *works at the Max-Planck-Institute for Gravitational Physics (Albert-Einstein-Institut) in Hannover, Germany and, after her PhD on LISA Pathfinder, now contributes to LISA. In addition to science, she enjoys swimming.*

References

[1] Buikema A. et al. (2020) https://link.aps.org/doi/10.1103/PhysRevD.102.062003
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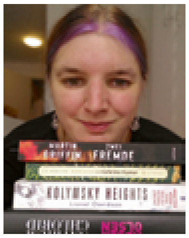
Making the most of your conference travel

Amanda Baylor

is a PhD student at the University of Wisconsin-Milwaukee where she analyzes gravitational-wave data to search for signals from merging compact binaries. In her free time, Amanda enjoys lounging on the shores of Lake Michigan and caring for her large collection of houseplants.

Jessica Steinlechner



is an associate professor at Maastricht University, where she works on mirror development. She likes reading, playing table tennis and decomposing car registration plate numbers into prime factors.

During your career, sooner or later you will encounter the question: To which conferences should I go? There are many more interesting conferences and meetings than you will have time to attend while still advancing your research. Of course, travel funds are also limited. Another important aspect is sustainability: Your institution or funding agency may already have – or be in the process of formulating – sustainable travel policies, and there's also your personal responsibility to consider.

So, how do you pick the conferences you do attend? Start by asking your supervisor! They will have advice on the specifics of your travel budget and also which conferences would benefit you the most at various stages in your career.

Different types of conferences:

- Collaboration-internal meetings such as the LIGO-Virgo-KAGRA collaboration meetings and meetings of other existing or forming communities (LISA, IPTA, Cosmic Explorer, Einstein Telescope etc.).
- National/local conferences of e.g. various physics societies.
- International conferences which can be gravitational-wave related (such as Amaldi) or very specific to your research topic (e.g. optics, solid state physics, astrophysics, etc.).
- Workshops which can exist as independent events or as part of a conference.

In a nutshell, collaboration meetings are important to stay up-to-date with your work, to meet collaborators, and to sometimes even work together right there.. National/local conferences usually cover a variety of fields within physics and often have a significant presence of industry, exhibitions etc. This is helpful to get an overview of the local research landscape, and if you're looking for local collaborators from industry. International conferences are a mixture of those two – with exposure to a wider audience. It can be more difficult to get a presentation slot, but they are often more esteemed than collaboration meetings and a presentation at an international conference is a good addition to your CV. Workshops can be quite varied in purpose: Usually they consist of interactive sessions, which are discussion-based. They can also be educational and serve to teach participants new skills or methods.

Online attendance is a great way to 'visit' meetings while saving both time and money, especially if you are just interested in a few presentations. Moreover, if you are invited to give a presentation, but cannot travel, it's worthwhile to check if there is an online option. However, networking is also an important aspect of conferences which isn't fully replaceable by online tools. Do not underestimate the networking aspect of an in-person conference: You might meet your future boss over lunch or in the coffee queue!

There's no clear answer to the question: Which conference is the most useful? - It's all about balancing, and throughout a PhD, aiming to attend each type of the conferences listed above at least once may be a good starting point. Then you can get your own idea of what's 'worth it'. Certain meetings may be more useful than others at specific stages of your career. You may want to advertise your new result or publication, network while searching for a job, make connections while transitioning to a new field, etc.

Before approaching your supervisor about attending a conference, it's a good idea to think of reasons why it's important for you to go. Networking is always a good reason, but what else? Are there any face-to-face working meetings you would participate in? Which collaborators would you aim to meet with? Would you give a presentation to publicize your recent work? Are there ways you could reduce travel costs, such as sharing lodging with someone else? There are many conferences to choose from, so propose those you find interesting and your supervisor will find beneficial for you.

To make the most of your budget, planning ahead is highly recommended. Most conferences occur with a certain frequency and sometimes it's known long in advance when and where they will take place. Attending a conference that's being held near your city, or a regional conference which occurs regularly in your area of the world, is a great way to keep costs down while still having an opportunity to present your work or meet others in your field. So place a reminder in your calendar and organize your travel early: Book flights and hotels first as prices can quickly skyrocket!

It's also worth checking if there are alternative sources of funding, such as a travel grant through your home institution or support from the conference itself. This would alleviate your budget, give you practice with the application process, and make a great addition to your CV!

Finally, you've decided where to go, so make the most of your stay! Plan ahead of time which sessions to attend. Don't hide in your hotel room between sessions, or spend all of your time with the people "from home", but try to meet new people and potential collaborators. And don't pass on social events! Stay for the whole duration of the conference. You don't want to waste funding to just stay for a day. Try to visit labs or collaborators who are located nearby. Conferences are not only career-developing experiences, but they're also fun! Make sure you take advantage of all the opportunities which they have to offer. Safe travels!

Tateyama, high mountains on east side of Toyama prefecture

LIGO-Virgo-KAGRA collaboration meeting in Toyama, Japan!

Our twice-yearly LIGO-Virgo-KAGRA (LVK) collaboration meetings have grown considerably over the years, gathering colleagues from across the globe. After a long tradition of rotating between North American and European meeting locations, this September the first Eastern LVK meeting is being hosted in Toyama, near KAGRA, in Japan!

To help you enjoy the meeting even more, this article shares some highlights to look for in the local area and at KAGRA, whether you are joining a tour now or hoping to visit in the future.

A (Virtual) Tour of KAGRA

KAGRA is a laser interferometer with a baseline length of 3 km. It is different from LIGO and Virgo because it is constructed underground at the Kamioka mine and cools the test mass mirrors to 20 Kelvin to reduce thermal noise. Observing Run 4 (O4) started on May 24, 2023, with KAGRA participating until June 21 and now resuming commissioning works, including laser replacement, scattered light countermeasures, cooling of the sapphire mirror, and so on. So please join our tour – in person or through this article – and see the real KAGRA!

Although it is still hot and humid in Toyama in September, you will be welcomed to KAGRA by the cool underground site and the regular sounds of cryo-coolers cooling the mirrors.

When you arrive you will see KAGRA's U-shaped tunnel entrance, which is 4 m wide and 4 m high. As you enter, you will feel the cool air peculiar to the tunnels.

Entrance of KAGRA

After walking 500 m through the tunnel, which is moist and wet underfoot, you will enter KAGRA's central experiment room, and may be surprised to find that the environment is warmer and more comfortable than the tunnel.

Takashi Uchiyama

is an associate professor of ICRR, the University of Tokyo, and the schedule manager and safety committee chair of KAGRA. He likes to eat and drink, and his recent self-confident work is pasta mixed with fresh tomato sauce and a few kneaded sesame seeds. It's also popular with his family!

Kazuhiro Yamamoto

is an associate professor at the Faculty of Science, University of Toyama. He is investigating thermal noise (especially from coatings), cryogenic payloads, sapphire mirrors and parametric instabilities. Recently he is excited because he can start to travel again, although we still have to be careful.

The main source of heat is filter-fan units in clean booths. But temperature alone does not make this a good environment – various efforts have been made, water control being the most important. Even in the experiment room, there is no escape from groundwater; we covered the walls of the room with waterproof sheets, and even then, any water that leaks out is dealt with individually to prevent it from wetting the floor.

In the central experiment room, you can see clean booths and vacuum chambers. Visitors will use stairs to climb over the vacuum ducts. From the top of these stairs, you can see the path to the laser source on one side and the Beam Splitter, in a tall vacuum chamber, on the other.

Mirror cooling is an important feature of KAGRA, so you will see the cryostat that is now installed on one of the mirrors (ITMY). If the commissioning work is going well, all the cryo-coolers will be operating, and the mirror will be cooled; KAGRA uses six cryo-coolers to cool one mirror.

The KAGRA test mass mirror is mounted on a 13.5 m "Type-A" suspension (see issue 17, p. 36 for more about the KAGRA suspensions). To install this tall suspension, KAGRA's tunnel has a two-layer structure, including an experiment room above the floor, and the top of the Type-A suspension placed on the upper floor. The 5 m of bedrock between the floors was drilled through to allow the vacuum ducts housing the Type-A suspension to pass from one level to the other. It is hard to see because it is hidden by the clean booth, but the vacuum duct extends from the top of the cryostat to the ceiling. Turning your attention back to the cryostat, you will notice a large flange with square boxes attached to it. These boxes contain components of sensors that monitor the movements of the mirror suspension system in the cryostat.

You can also look into the 3-km Xarm tunnel. To go back and forth along the arm, we use a small, rare electric car called T3. Like the entrance tunnel, this tunnel was also built in a U-shape, 4 m wide and 4 m high, with a vacuum duct 80 cm in diameter. The tunnel was excavated using the New Austrian Tunneling Method (NATM) with blasting. The walls were only coated with mortar for reinforcement, so the distorted surface created by the blasting can be seen.

Gagaku

During the LVK meeting networking event, attendees will see ancient Japanese music and dance called Gagaku. Gagaku is a fusion of ancient Japanese music and music from China, Korea, and other Asian countries, which was completed around the 10th century. One of the ancient Japanese music that Gagaku is based on is Kagura, which has the same pronunciation as KAGRA. This is the reason why we are offering Gagaku to you. In Gagaku, you will enjoy music and

***Top:** The 3 km X-arm tunnel was built in a U-shape, 4 m wide and 4 m high, with a vacuum duct 80 cm in diameter.*
***Below:** Walls of the experiment room are covered with waterproof sheets, and even then, any water that leaks out is dealt with individually by a receptor.*

Welcome to KAGRA

by Takashi Uchiyama & Kazuhiro Yamamoto

Gagaku Performance.

Gokayama, Gokayama, World Heritage Site

dance performed by priests in beautiful traditional costumes. Traditional and rare instruments are also used for playing Gagaku, please pay attention to them. We hope that the fantastic atmosphere created by Gagaku with a history of 1000 years will remain in the memory of this meeting.

Exploring Toyama

Toyama city is the nearest city to the KAGRA site (40 km, 1 hour drive), and about 200 km from the largest three cities in Japan: from Tokyo, it takes 2 hours by bullet train ("Shinkansen" in Japanese) or 1 hour by plane, while from Osaka or nearby Kyoto, it takes 3 hours by special express train.

About 0.4 million people live in Toyama city, the capital of the Toyama prefecture. The University of Toyama is an affiliate of the KAGRA collaboration, and the Toyama International Conference Center, which is the venue of the LVK meeting, is in the city center, opposite Toyama Castle. It takes just 10 minutes to travel from Toyama station to this Conference Center by bus or tram.

On the east and south side of Toyama, there are many high mountains (one on the south side contains the KAGRA interferometer!), while to the north is the sea of Toyama Bay. Yasuto Inagaki, a famous photographer, recently shared his beautiful photos in Toyama on his Twitter (@inagakiyasuto). Although he writes in Japanese, you do not need the language to enjoy them! Toyama is also famous because of heavy snow in winter, including at KAGRA. It is not easy to find such low-latitude heavy snow in the world.

Foods in Toyama are famous, especially sushi (also Japanese Sake)! There are many sushi restaurants. About three hundred years ago, the trout sushi was a tribute to Shogun in Edo (present-day Tokyo). Other famous local sushi includes firefly squid, white shrimp, crab, and yellowtail.

For a day trip, I recommend Kurobe Dam on the east side of Toyama prefecture. This dam and hydropower plant is one of the largest in Japan. Other famous spots on the east side are Unazuki Onsen (hot springs) and Kurobe Gorge Railway, while to the south west of this prefecture is Gokayama (Shirakawa-go in Gifu prefecture is nearby). This is the only world heritage site in and near Toyama prefecture, with old Japanese small villages.

Beyond Toyama prefecture, Takayama city (2 hours train ride) is a small but nice place for sightseeing (and hosted the 2014 Gravitational Wave Advanced Detector Workshop). Meanwhile Kanazawa city, capital of Ishikawa prefecture next to Toyama prefecture, is known for Kenrokuen (famous Japanese style garden), Buke Yashiki (old samurai's houses), Kanazawa castle, and Chayagai (historical area). It takes 20 minutes by Shinkansen or 1 hour by local train from Toyama station.

We wish for you to enjoy not only the LVK meeting, but also your trip in Japan and near Toyama! So please join our tour - in person or through this article - and see the real KAGRA!

Choosing a career path in finance

Ask anyone who knows me what it is that I did during my PhD, and they might struggle to paint the full picture, but they will certainly immediately shout out "gravitational waves!".

My endless enthusiasm for gravitational waves is known to many, and I was indeed lucky to join LIGO at an exciting moment in time. Focusing on gravitational-wave background, I developed methods for its detection and studied implications for early-universe physics, from population III stars to first-order phase transitions.

Towards the end of my PhD, like many I was at a crossroads. Undecided of where I want to go next or if the academic path is for me, I spent a lot of time exploring other options. I concluded that it is time for a change, a fresh start and a new challenge. With great heartache, I wrapped up my thesis and I said goodbye to my LIGO credentials.

I am now a Quantitative Researcher (or Quant for short) at Nomura, a Japanese investment bank. Choosing an alternative career path was not easy. It "clicked" during the interview process when I had to give an hour-long technical seminar on a topic of my choosing. Of course, I used the opportunity to talk about gravitational waves, and I later found out my slides with a simulation of a binary black hole merger caused quite the stir within the Nomura IT team. As I delivered the seminar, I was met with brilliant questions from the audience who shared my enthusiasm, and at that point it was clear that I would enjoy working with this team.

Katarina Martinovic finished her PhD at King's College London, and now works as a Quantitative Researcher at Nomura. She enjoys playing rugby, dancing and frequenting her beautiful home, Montenegro.

Unexpectedly, I entered the world of finance. If, like me, you did not pay much attention to financial markets during your physics career, it is like learning a new language. Week one was a crash course in what an investment bank does, and what Nomura has to offer. In a small team of new joiners, we simulated an initial public offering (where a private company offers its shares to the public for the first time), and from there we mimicked secondary trading of the company's stocks and shares!

My daily job surprised me with its sense of familiarity. I am surrounded by people with similar backgrounds and interests to me, and we spend our days solving problems and building models that best describe the world around us. Along with the research aspect, there is continuous engagement with traders to support their daily business. I specialise in foreign exchange, referred to as "FX", where the geopolitical impact on currency exchanges makes for an interesting line of work. As part of the Quant team, I develop the C++ library used to price FX options like simple calls and puts or more exotic structured products. For example, a call is a contract that, at expiry, gives the buyer the "option" to exchange two currencies at a previously determined FX rate.

Eight months into my role and I am really enjoying myself. Naturally, my Twitter feed is still full of physics research that I read with great pleasure, and no matter where my career path takes me, I will eagerly await the first detection of gravitational-wave background!

Career Updates

Nancy Aggarwal has started a faculty position at UC Davis. Her group will be building precision measurements experiments to search for gravitational waves and dark matter. The group will also be building new pipelines to look for ultralight primordial black holes in LIGO, and using auxiliary channels in LIGO to look for direct interaction of dark matter with the LIGO detectors.

Tessa Baker will be moving to take up a professorship at the Institute of Cosmology and Gravitation, University of Portsmouth, UK starting October 1st, 2023. She is looking forward to bringing her cosmology and tests of gravity research to the already thriving LSC group there.

Sylvia Biscoveanu graduated with her PhD from MIT in June and will be continuing her LIGO research as a NASA Einstein fellow at Northwestern's CIERA in the fall.

Virginia d'Emilio has completed her PhD at Cardiff University and will be coming to Caltech as a Postdoctoral Scholar.

Bruce Edelman completed his Ph.D. at the University of Oregon in June and has started a postdoc in Biology, also at UO.

Eliot Finch has defended his thesis at the University of Birmingham, titled "Black-hole Ringdown: Quasinormal Modes in Numerical-relativity Simulations and Gravitational-wave Observations". He will be moving to Caltech where he will continue ringdown work as well as starting new projects on inferring neutron star equations of state.

Andre Guimarae completed his Ph.D. at Louisiana State University and will start a postdoc at LSU.

Rico Lo successfully defended his PhD thesis at Caltech in early August and will be a postdoctoral fellow at the Niels Bohr Institute in Copenhagen.

Dr. Elisa Maggio was recently awarded a Marie Skłodowska-Curie Postdoctoral Fellowship for a project on "Testing the horizon of black holes with gravitational waves" (ThorGW). The fellowship will be at the Max Planck Institute for Gravitational Physics (Albert Einstein Institute) in Potsdam, Germany with a secondment at the Niels Bohr Institute in Copenhagen, Denmark. The research will provide novel tests of general relativity concerning the location of the horizon in compact objects with current and next-generation detectors.

Kara Merfeld completed her Ph.D. at the University of Oregon in June and has started a postdoc at Texas Tech University.

Arianna Renzini is leaving Caltech to take up a Marie Curie Fellowship at the University of Milan.

Lucy Thomas has successfully completed her PhD viva at the University of Birmingham. She works on waveform modeling and data analysis, and is due to start a postdoc in the LIGO Lab at Caltech from September.

Awards

Prof. Dr. Tim Dietrich has received the IUPAP Early Career Scientist Prize in General Relativity and Gravitation, and a scholarship from the Daimler and Benz Foundation.
https://www.aei.mpg.de/998649/erfolgreicher-nachwuchswissenschaftler

Anamaria Font, Professor from the Central University of Venezuela and long-term scientific guest at the Max Planck Institute for Gravitational Physics in Potsdam, has been awarded the L'Oréal-UNESCO For Women in Science International Award for her important contributions in theoretical particle physics, in particular to the study of string theory. The award ceremony took place on June 15th, 2023, at UNESCO's Headquarters in Paris. https://www.aei.mpg.de/1049295/loreal-unesco-award-for-anamaria-font

Dr. Elisa Maggio received a prize from the Amaldi Research Center at La Sapienza University in Rome for her outstanding thesis on tests of general relativity.
https://www.aei.mpg.de/1014138/elisa-maggio-receives-award-for-her-doctoral-thesis

Hao-Jui Kuan, postdoctoral researcher at the Max Planck Institute for Gravitational Physics (Albert Einstein Institute) in Potsdam, has been awarded the Dr. Friedrich Förster Prize for his outstanding dissertation. The prize honors young scientists in the fields of physics and physical chemistry who have completed their work in Tübingen within the last three years.
https://www.aei.mpg.de/1064589/foerster-prize-for-hao-jui-kuan

Dr. Benjamin Leather has received the IOP Gravitational Physics Group Thesis prize for his work on accurate waveforms for LISA.
https://www.aei.mpg.de/1017532/thesis-prize-for-benjamin-leather

Susan Scott (Distinguished Professor at the Centre for Gravitational Astrophysics, ANU) has been awarded the Australian Institute of Physics Walter Boas Medal and the Royal Society of New South Wales Walter Burfitt Prize. This prize is awarded every three years for research in pure or applied science deemed of the highest scientific merit.
https://www.anu.edu.au/news/all-news/susan-scott-wins-australian-institute-of-physics-medal

Viktor Svensson, former PhD student at the Max Planck Institute for Gravitational Physics (Albert Einstein Institute) in Potsdam, now post-doctoral researcher at Lund University, is being honored with the Otto Hahn Medal for his outstanding doctoral thesis. Svensson studied the question of when a system can be described as fluid. This is crucial if we are to understand, for example, heavy-ion collisions in which a quark-gluon plasma forms that behaves as a relativistic fluid. The award was presented on June 21 during the annual meeting of the Max Planck Society in Göttingen.
https://www.aei.mpg.de/1053815/otto-hahn-medal-for-viktor-svensson

New LSC positions

Patrick Brady has been re-elected LSC spokesperson.

Peter Shawhan has been elected Elected Member of the Management Team.

Greg Ashton has been elected LSC co-chair of the CBC working group.

Vuk Mandic has been elected LSC co-chair Stochastic.

Ryan Patrick Fisher has been elected LSC co-chair Burst Search Working Group .

Jess McIver has been appointed LSC deputy spokesperson.

Other News

Einstein Telescope Scientific Collaboration leadership elected **Michele Punturo** (INFN) and **Harald Lück** (Leibniz University Hannover) to serve as coordinator and vice coordinator, respectively.
https://www.aei.mpg.de/1013491/einstein-telescope-scientific-collaboration-leadership-elected

Stephen C. McGuire, Southern University Endowed Professor of Physics Emeritus, has been inducted into the Phi Delta Kappa (PDK) International professional association for educators. Founded in 1906, PDK focusses its work on the tenets of research, leadership, and service, particularly within the arena of public education. This follows Stephen's recognition by the local PDK chapter (#0138) with its "Outstanding Scientist in Education" awarded in 2016.
For more on PDK International see:
https://pdkintl.org/

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Editors: Swetha Bhagwat, Georgia Bolingbroke, Kim Burtnyk, Shreevathsa Chalathadka Subrahmanya, Debarati Chatterjee, Storm Colloms, Raed Diab, Chiara Di Fronzo, Andreas Freise, Paul Fulda, Gabriela González, Rachael Huxford, Tanazza Khanam, Nutsinee Kijbunchoo, Sumeet Kulkarni, Susanne Milde, Mckenzie Munn, Sascha Rieger, Mitchell Schiworski, Eyal Schwartz, Natalie Williams

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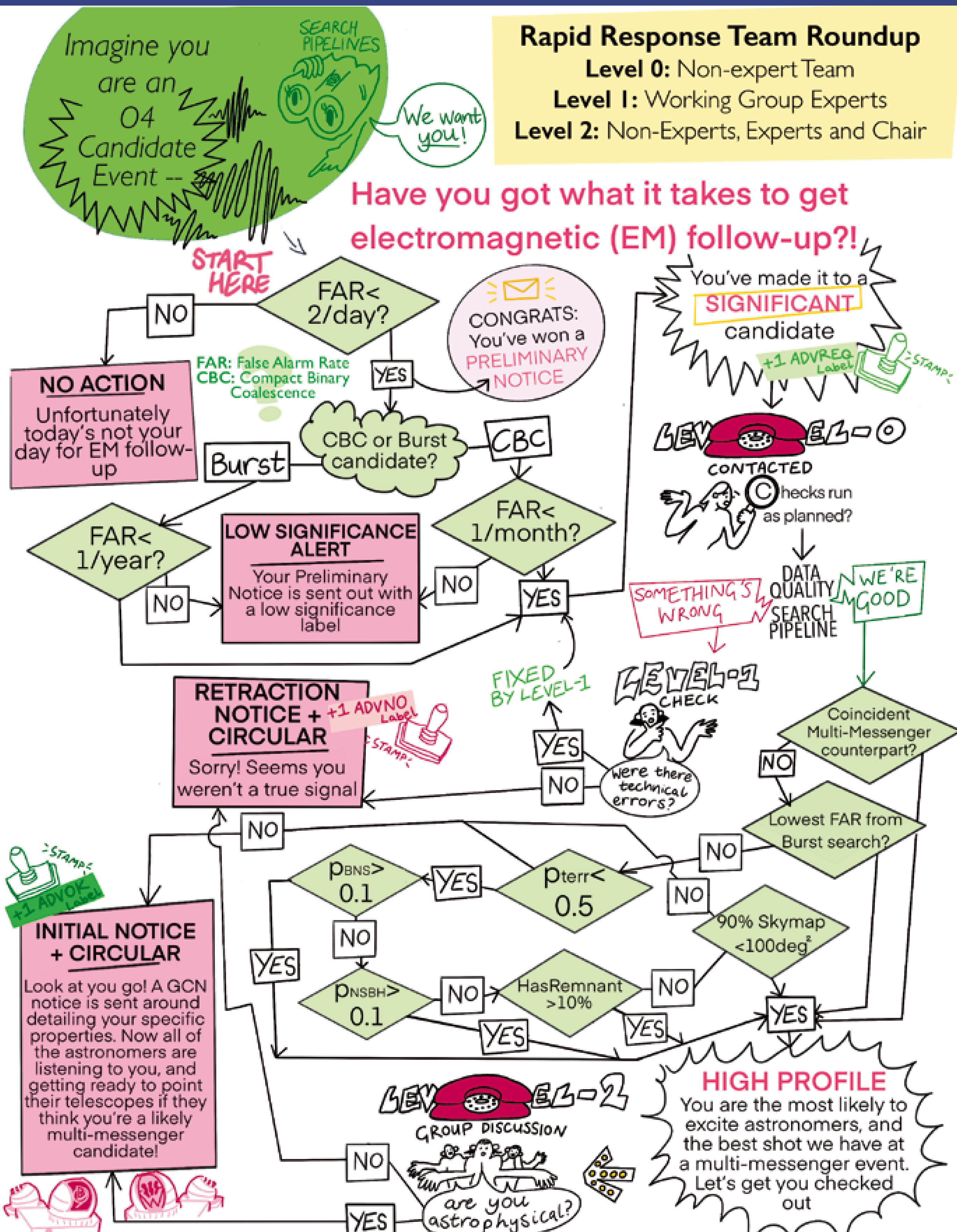
The entrance gate to the site of the European Gravitational Observatory (EGO) and the Virgo detector, during the inauguration of Virgo, on July 23rd 2003. The flags of the two founding members are flying above the west arm of the detector. (Photo courtesy of EGO/Virgo).

How it works: The journey of a gravitational-wave candidate



p_{terr} : probability of signal being of terrestrial origin

p_{BNS} : probability of signal being from a binary neutron star merger

p_{NSBH} : probability of signal being from a neutron star-black hole merger

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by Storm Colloms with the RRT managers: Francesco Di Renzo, Keita Kawabe, Hisaaki Shinkai, Peter Shawhan