LSC LIGO Scientific Collaboration

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LIGO MAGAZINE

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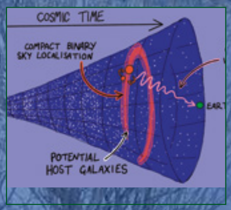

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Front cover

"Although a mild winter thus far, we have had a little snow fall over the season. This cover photo is of a fresh dusting of snow along the X-Arm of the LIGO Hanford Observatory at sunset from December 2023. This snow would melt within 24hrs." – Corey Gray, LIGO Hanford.

Top inset: Parameter estimation helps us to find out what kind of source produced the gravitational waves we observe. One kind of source are binary black hole systems, as shown in this artistic representation by Laurence Datrier.
Article on pp. 6-7.

Bottom inset: Gravitational waves can also be used for cosmology.
This illustration by Storm Colloms shows the Dark Siren method. Article on pp. 8-9.

Bottom left (diagonal) inset: A LISA test mass cube. Article on pp. 14-15.

Image credits

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Cover: Main image: Photo of the LIGO Hanford Observatory by Corey Gray (note that the image is reversed for artistic purposes).
Top inset: Artistic representation of a binary black hole system by Laurence Datrier). Bottom inset: Dark Siren illustration by Storm Colloms.
Bottom-left (diagonal): LISA test mass photo from ESA, CC BY-SA 3.0 IGO.

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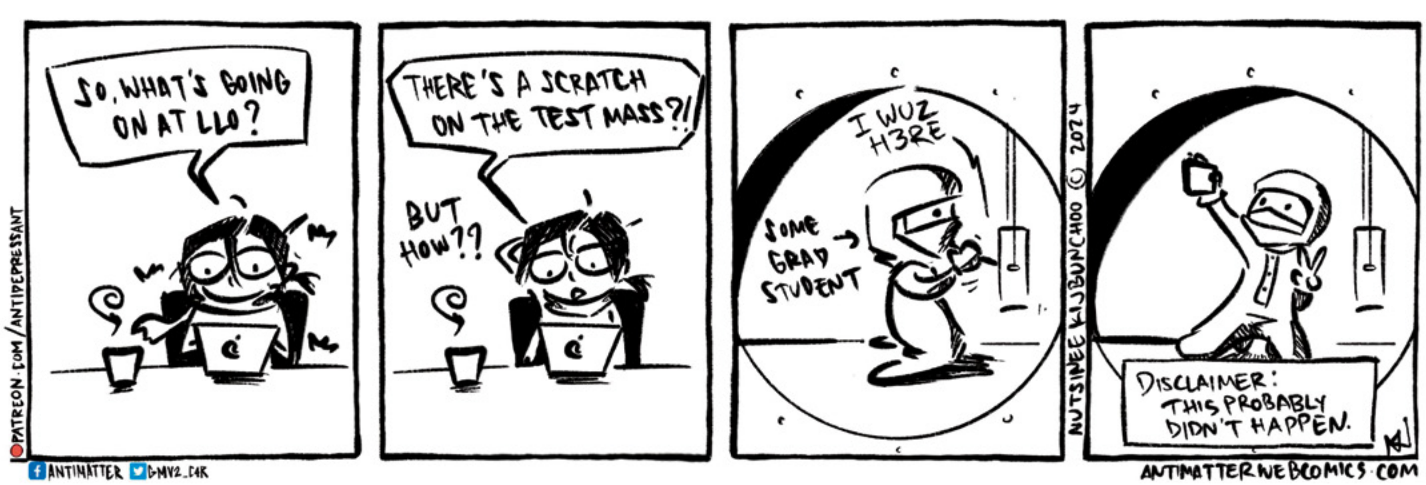
by Nutsinee Kijbunchoo



Welcome to the 24th issue of the LIGO Magazine!

Hannah Middleton
Editor-in-Chief

Anna Green
Deputy Editor-in-Chief

Welcome to the twenty-fourth edition of the LIGO Magazine! With the completion of the first part of Observing Run 4 (O4a), we discuss the run so far and what we can look forward to in the rest of O4. Catching up with Natalie Williams and Jessica Irwin, we hear about their experiences at the forefront of scientific research as part of the O4 Parameter Estimation rota. And did you know that gravitational waves can be used to do cosmology? Maria Lisa Brozzetti is our guide to learning about the origins of the Universe with gravitational waves.

At the time of writing, a commissioning break is taking place at the LIGO observatories. Nutsinee Kijbunchoo tells us what's been happening and why commissioning breaks are crucial for gravitational-wave observatories. As Virgo gears up to join O4, Anna Green interviews Virgo Spokesperson Gianluca Gemme on "Virgo's road to O4 and beyond". And Thomas Roocke takes a closer look at some of the optical components used in gravitational wave detectors for "How it works: The SAMS deformable mirrors"

Making our research accessible is important for allowing everyone equal opportunity to appreciate the wonders of astronomy. Nic Bonne tells us how the Tactile Universe project is creating educational resources designed to make astrophysics accessible to blind and vision impaired people. We also take a dip in the pool in "Making a Splash with Gravitational Waves" by Graeme Eddolls.

Earlier this year, the LISA Mission passed the critical milestone of Adoption by the European Space Agency. Nora Luetzgendorf tells us about what this landmark means and the long road leading to it in this issue's Meanwhile in Space. As humanity strives to return to the Moon, the possibility of a lunar gravitational wave observatory is also being explored as told by Joris van Heijningen.

Did you know that the techniques used in searching for continuous gravitational waves have a lot in common with cleaning up audio recordings? Matt Pitkin tells us all about working in audio forensics in Work After LIGO. Plus, going behind the scenes at LIGO, we find out about the business professionals supporting the science in the "Business End of Big Science".

In the first in our Climate Change Conversations series, Victoria Grinberg discusses how all scientists can contribute to tackling the climate crisis. Finally, finding balance between work and life can be a struggle. In LAAC Corner, Jessica Steinlechner and Mikhail Korobko discuss parenting in academia, with contributions from many LVK members.

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

In the LIGO Scientific Collaboration (LSC), we work together to design, build and operate the most sensitive gravitational-wave detectors. We strive each day to overcome technical challenges that limit our ability to observe further and extend our understanding of the Universe. We achieve so much when we work together. And this brings us to one of the biggest challenges we face – maintaining a welcoming, supportive, and professional collaborative environment.

We are proud of the progress our Collaboration has made toward meeting this challenge and we want all of our collaboration members to feel welcome and respected. On occasion, any one of us may slip up. It is often in everyone's best interest to communicate concerns informally to each other when that happens. While it can be difficult to transmit and receive such messages, open communication can help improve our Collaboration's environment. If you're aware of a situation where someone may benefit from feedback but you're not comfortable crafting or delivering it, the Ombudspersons are available to provide independent, confidential advice and can help mediate difficult conversations.

In most cases, an open conversation is all that is needed. Nevertheless, it is important for the Collaboration to address any issues that are not resolved by informal discussions. Any LSC member may bring a concern or complaint that involves the Collaboration to their LSC Group leader, to working group chairs, or to the Spokespersons. The LSC member need not be the aggrieved person; they may have observed something of concern that they think should be addressed. We are ready to support you. Unresolved issues undermine our ability to work together and live up to our Code of Conduct.

Returning to our scientific mission, the current observing run has been going very well. We identified and publicly released 81 significant gravitational-wave candidates so far. For the first time, we have also been releasing low-significance candidates in low-latency. Work is ramping up on the ambitious list of observational-science papers that we have planned. We encourage everybody to get involved; people are needed to assist in the preparation and review of the papers and associated materials. Commissioning activities at the Hanford and Livingston sites are currently ongoing. We will begin observing again in early April and plan to continue through January 2025.

As we look beyond the current observing run, we are exploring changes to our partnership with Virgo and KAGRA to address deficiencies in our current LVK organizational structure. One bold idea being discussed is to establish a single, global organization with a unified governance structure and common expectations of all groups whether they are currently in the LSC, Virgo, or KAGRA. We look forward to discussing this with everybody over the coming months.

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

O4 – On parameter estimation duty

The first part of the fourth Observing Run (O4a) took place between 24 May 2023 and 16 January 2024. During O4, many people in the collaboration volunteer to be part of the parameter estimation (PE) rota. Rotating on a weekly basis, members of the collaboration ranging in experience from PhD students to data analysis experts, monitor and undertake the PE of incoming events. PE involves analyzing the gravitational wave signal and then inferring the properties of the source that made the signal. With PE, we want to find out things such as whether the signal came from a binary black hole or a binary neutron star merger, how massive were the binary components, where in the sky were they, and how far away. Initially, all events trigger an automatic PE, however, sometimes a glitch or unsuitable settings means rota members must discuss the next course of action and manually set up PE analyses. Taking part in this front line activity of running the initial PE means not only experience for junior researchers, but also working at the forefront of scientific research as these never-before-seen events come in for the first time. Here PhD students Jess and Natalie discuss their experiences being on the O4a rota and their stories from that time.

Natalie: So was this your first time on rota then?

Jess: Yeah, this was my first time ever being on the PE rota. I signed up after some others in my office in Glasgow had participated in earlier weeks of the observing run and had found it really interesting. Have you taken part before?

Natalie: When I first started my PhD it was just after O3b (the second part of Observing Run 3), so the rota was wrapped up officially but there were some events that popped up when looking through past data. I got the opportunity to do some PE for the catalog, which was exciting!

Jess: How did O3 catalog runs compare to your O4 rota experience? I joined the collaboration in 2021 so O4 is my first experience of an active observing run.

Natalie: It was different because the analysis software we used has changed. In O3, I was using LALInference, which is written in C. Now we have transitioned to using the new PE software called Bilby (which is python based). I'd never used C and I was brand new to the process which was a challenge but it was great to see how it all worked. In the end the data didn't contain a real signal but a glitch so not much was on the line! This time around I had a lot more runs under my belt and more experience with Bilby so I was excited to get stuck in! Also, last time I was working remotely because of COVID and this time I had an office of people who had been on the rota as support, which really made a difference. How did you find your rota group?

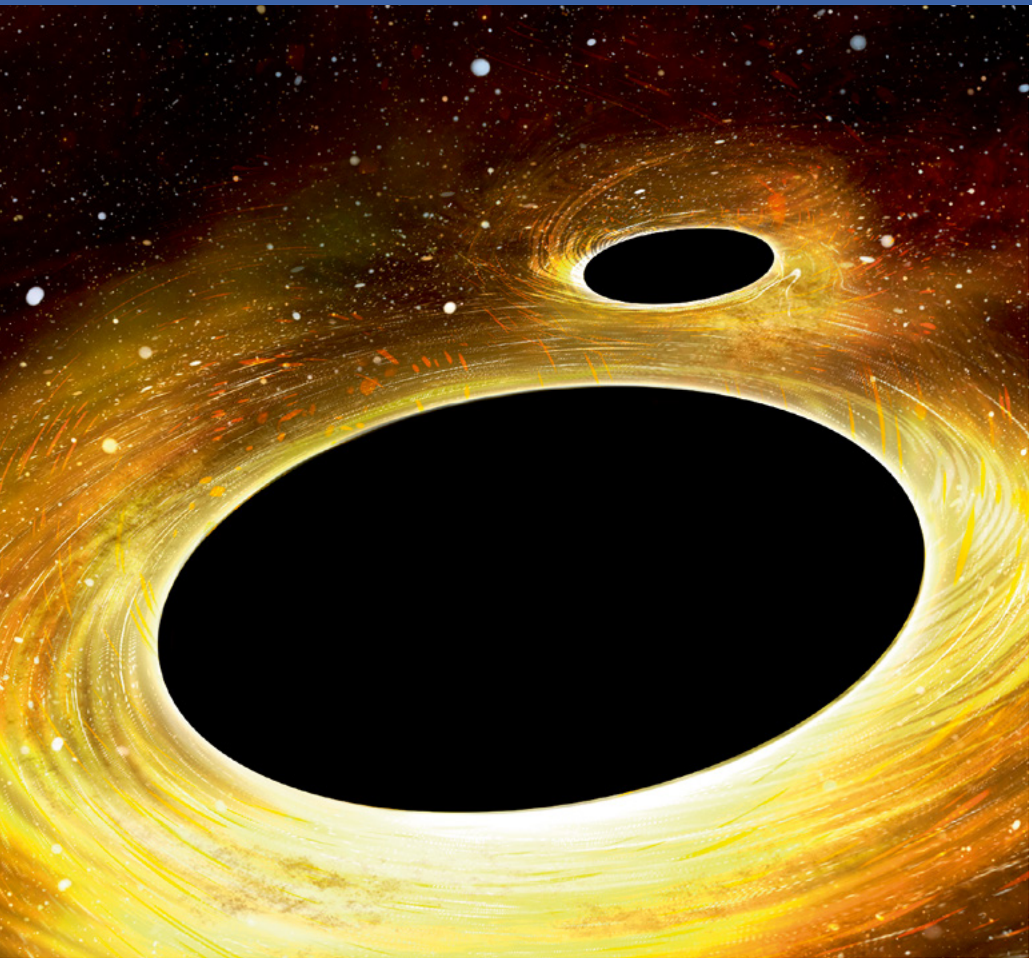
Jess: Most of my rota team were also based in the UK/central Europe so we were lucky to be able to call regularly. The PE expert on our team was in east coast North America so this lined up nicely too! Our week was a little bit more active so we kept in contact often to discuss the new events that had come in. Most things were automated well so not much needed to be done but we also did some additional

Natalie Williams

is a PhD student at the University of Birmingham studying gravitational waves from neutron star mergers. In her research she asks "how squishy are neutron stars?" and creates models to someday find the answer. In her spare time Natalie likes going to the pub, solving a cryptic crossword, and crocheting on her houseboat.

Jessica Irwin

is a PhD student at the University of Glasgow using Machine Learning to understand the nature of matter inside neutron stars from the gravitational waves they emit when they merge. Outside of research, Jessica enjoys making dinner for her friends and going to ballet class.



An artistic representation of a binary black hole system by Laurence Datrier.

investigations. This meant we had daily calls to coordinate who was investigating what, for example, what waveform model we wanted to test and what settings for the sampler we were using. These were really useful, especially as someone who doesn't use Bilby every day. It was also nice to work with other members of the collaboration who I hadn't met before, especially as a student. Was your week active with events?

Natalie: That sounds like you had a busy week! Our week was very quiet – when you're at the whim of the Universe sometimes it can be a little quieter than you hope. I had a great rota team and despite not needing to meet too often, it was great to connect with people I might otherwise not have met. Rather than looking at new events coming in we mostly re-analyzed events from previous weeks where the settings needed tweaking. That's exciting in itself because you can really see how much the settings affect the results – and there's nothing really like seeing your results for the first time! PE can take days or sometimes weeks to complete so the suspense can get to you. Also, I had my phone set to receive event alerts as well so I was in suspense all week with every text!

Jess: Me too! I had alerts left on from being on the Rapid Response Team (take a look at issue 23 to find out more) over the summer, where I helped check triggers as soon as they are identified in the detectors. Once we are confident that the trigger is a signal, we send an alert out via the General Coordinates Network to other observatories in case there is a possibility we will see the signal in another form. This was also cool, but much more time sensitive, so quite stressful! So I understand the stress that comes with the text alerts.

Natalie: My office mate has their alerts play a chirp sound every time an event comes through – that was exciting. Seemed I couldn't even get a text back from the Universe, personally! It's really unpredictable but that's the fun of it, being literally at the forefront of science is exhilarating.

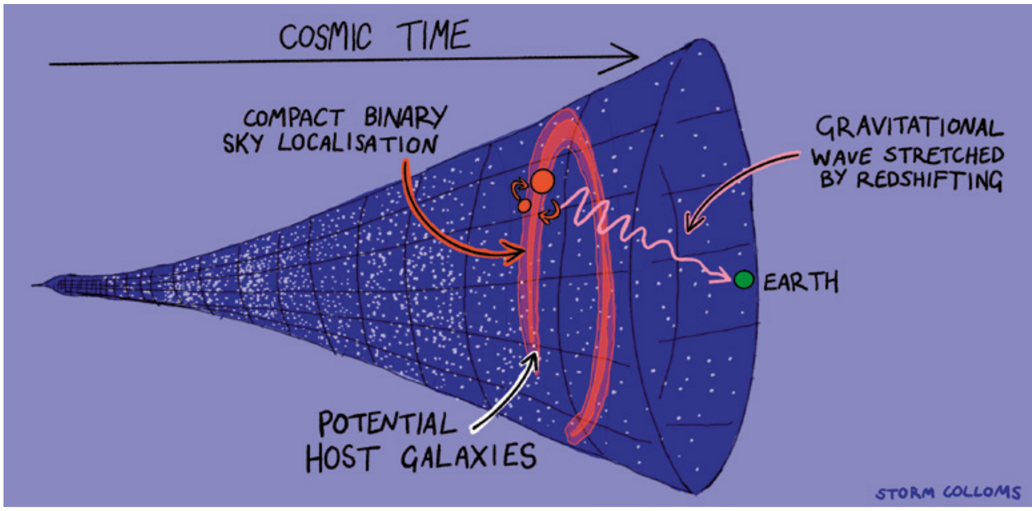
Jess: It's really exciting to be on the team doing some of the very first analyses of brand new events, especially when you initially have no idea what the results could be. Do you have any wisdom for anyone taking part in the PE rota in the next half of the observing run?

Natalie: I think looking forwards to O4b I'd say don't be afraid to get stuck in with PE, there's tutorials for anyone interested to look through and then when you're on rota your team is there to guide you every step of the way.

Jess: Yes! And to get to be some of the first people looking at the results that could end up in all kinds of exciting papers; studying the gravitational wave sources as a population, testing General Relativity, cosmology with gravitational waves – all these groups depend on people in the PE rota being on call and acting on the alerts that come through. Their investigations go on to support the further work these groups do so that we can better understand the nature of the source of the signal and inform the wider astronomy community.

Collaboration members who would like to be involved in the PE rota for the second part of the fourth Observing Run (O4b) should keep an eye on the Compact Binary Coalescence (CBC) PE group's updates in advance of and during the run.

Chasing the Origin of the Universe



▲ *An illustration of the Dark Siren method used in gravitational wave cosmology. Even without electromagnetic counterparts, the gravitational waves from compact binaries can be used to study the Hubble constant by comparing their sky localisation to potential host galaxies.*

Observing Run 4 (O4) brings many more detections of Compact Binary Coalescences (CBCs). While these detections may feel less exciting than the very first ones as they become part of our day-to-day lives, this abundance of events is pivotal in gravitational-wave (GW) cosmology. GWs are a key tool for addressing big questions about our universe such as how to solve the Hubble tension. This tension is a discordance between differing measurements of the Hubble constant: the velocity at which the universe expands. The Hubble constant relates distances to redshift values, and is a key concept for cosmologists.

So far, the binary neutron star merger GW170817 has remained unique in the GW catalog due to being detected alongside an electromagnetic (EM) counterpart. It was a multi-messenger detection with both GW and EM observations. This feat allowed telescopes to identify the host galaxy of the merging stars as NGC 4993. Consequently, the redshift could be determined. This was a huge breakthrough for GW cosmology, as the mass-redshift degeneracy was broken with the EM counterpart. It marked a long awaited achievement — the first measurement of the Hubble constant using information from a GW signal!

Many years before that first multi-messenger detection, Bernard Schutz understood a crucial aspect of inferring cosmological parameters. The distance to GW sources could be directly measured with high accuracy by interferometers, such as those of the LIGO-Virgo-KAGRA Collaboration. This allows researchers to estimate astronomical distances without the use of relative methods known as the cosmic "distance ladder". Because of this peculiarity CBCs earn the name of "standard sirens" in analogy with the luminous stellar explosions Supernovae Type Ia, named the astronomical "standard candles". But, we also require something that isn't directly measurable from the GW signal: the redshift of the source. This information is closely linked together with the masses of the two merging objects in their source frame, something we don't know without knowing the redshift. This is called the "mass-redshift degeneracy". Indeed, the masses we measure in the detectors have been shifted by the expansion of the universe. We need to know the details of this expansion to calculate the source frame masses.

On the one hand, the multi-messenger event was unique, but on the other, we have recorded almost a hundred "dark sirens" with no bright EM components so far. Because of the lack of direct redshift measurements with these "dark standard sirens", the GW cosmology community has been working on developing sophisticated techniques to infer the cosmological parameters and investigate the black hole population. The degeneracy between mass and redshift can be broken

Maria Lisa Brozzetti

is currently pursuing her PhD at the University of Perugia, Italy, with a research focus spanning from multi-messenger astronomy to cosmology. Her many hobbies include watercolor drawing and sketching, design, yoga, experimenting with new cooking recipes, and trying to squeeze more hours into her day!

in two ways. In the "spectral siren method" researchers assume upfront how the CBC masses change throughout the universe, and then the redshift information is derived from the relationship between source-frame and detector-frame masses. Otherwise, using the "catalog method", we can assume that each of the binary black hole mergers occurs in a galaxy which we can observe in the EM and is collected in astronomical catalogs[1]. We can then use these galaxies to trace the redshifts of the GW events. This host galaxy guessing game is a lot more complicated than a direct redshift measurement from a kilonova! Nevertheless, the latest analysis of GWTC-3 events results in a notable 42% improvement in the accuracy of the Hubble constant measurement compared to the GWTC-1 outcome.

The Hubble tension looks easier to solve with the O4 run, as observing more GWs allows us to reduce the current systematics and proceed towards accurate and precise GW cosmology. Detecting more "dark sirens" allows us to refine our assumptions about the black hole binary population. This, alongside adding more galaxies to our catalogs, will be the main driving force behind the improvements in GW cosmology. Of course, this comes along with important new challenges: gathering additional GW observations, refining our analytical methods, and exploring the cosmological processes with the advent of large ground-based observatories such as Vera Rubin or telescopes in space as Euclid.

LIGO 2024

[1] *Such as the Dark Energy Spectroscopic Instrument Legacy Survey or the 2 MASS Photometric Redshift Catalog*

[2] *GWTC stands for gravitational wave transient catalog. Find out more about GWTC-3 and GWTC-1 in LIGO Magazine issues 20 and 14, respectively.*

Lessons from the Gravitational Wave

What's in life's ups and downs?
All are dealt a mix of smiles and frowns,
Ride them at your will; be brave,
Lessons from the gravitational wave,

Disparity perceived through the lens of bias yields acrimony,
Equanimity arises by realising there is an underlying harmony,
Energy that powers stellar core also carries my pace,
Lessons from the gravitational wave

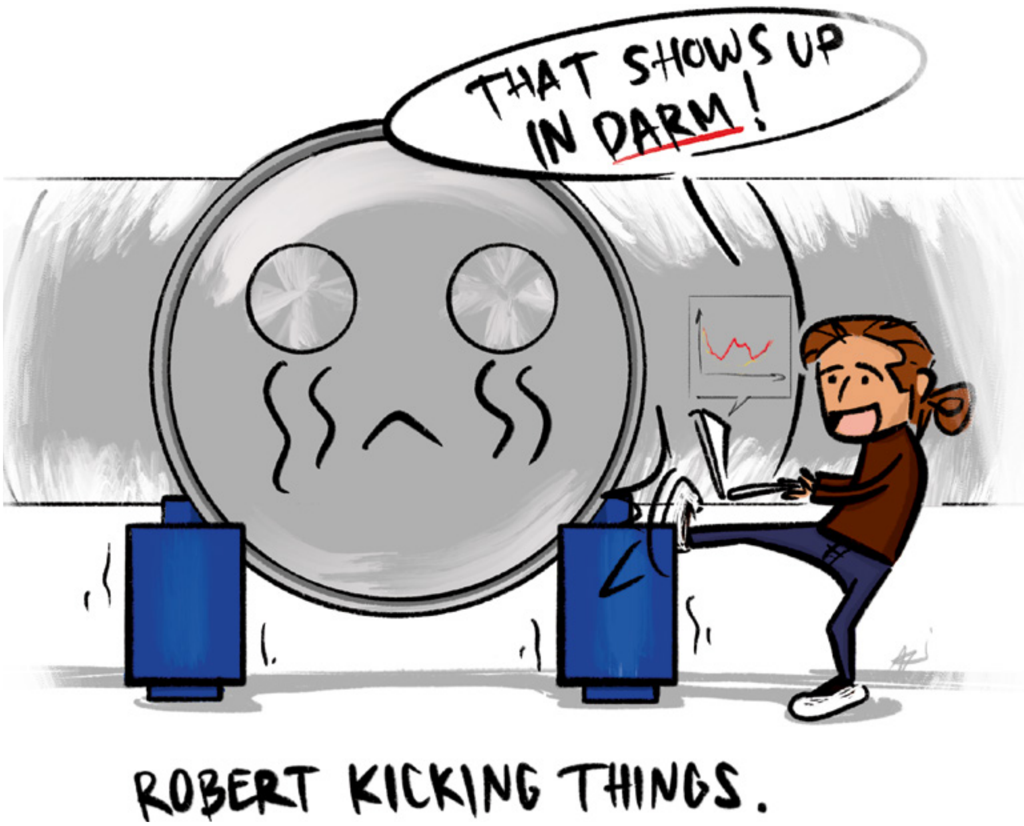
You may go unappreciated, unnoticed in your long stride,
And yet a few in you will have their faith confide,
Appreciate, notice, light up their beaming face,
Lessons from the gravitational wave,

But, beware pride should not take you,
Inebriated from the praising words of the few,
Remain untethered; march to the unending grace,
Lessons from the gravitational wave.

–Vaibhav Tiwari

Vaibhav Tiwari is a research fellow at the University of Birmingham. He enjoys playing cricket and distant walks.

Why have them? The 2024 Commissioning break



Have you ever wondered why we have commissioning breaks? Well, I have. I thought we were having these breaks because there are things to fix. That turned out not to be true. There are (Mpc) goals to be reached at every observing run. If the detectors' performances aren't optimal due to imperfect mode matching or noises (and they probably never will be), scientists have ideas on how the detectors can be improved. Sometimes people think of LIGO as telescopes that can just keep on running and detecting black holes. We still have much to learn about the detectors themselves with many unsolved mysteries to investigate. There have been many PhD theses and generations of graduate students made from these detectors and that will continue to be the case. We will never stop exploring and improving the science behind the LIGO detectors. Not for a while.

Nutsinee Kijbunchoo

is currently a postdoc at the University of Adelaide. Her current project is to measure various samples of glasses in search of the future detector test mass material. Every now and then she comes back to LIGO Hanford to work on the squeezer. In her spare time she enjoys going to beaches, eating pie floaters, and sampling the best wines Australia has to offer.

I recently met Daniel Sigg, LIGO Hanford (LHO) Head Commissioner, over the holiday break. Here are some of the wisdoms I've collected for this article with additional notes from myself for the topics that need further explanations. A disclaimer: Some parts of the conversations were transcribed from memories. We were at least half sober.

(**N** = Nutsinee, **D** = Daniel)

N: So why are we having a commissioning break?
D: Stuff to do then proof it. So, we do it. Necessary? No.
It was agreed at the start of the run that we were going to have a two month commissioning break.
N: And we're not gonna have it (commissioning break) again?
D: No.
N: Even if things break?
D: That's not a commissioning break. That's a "fix it" break. If nothing breaks you don't need to fix it.
N: So, at LHO I know that a squeezer is getting a new PMC (Pre-Mode Cleaner). OMC (Output Mode Cleaner) is also being replaced because of an unexplained loss?

(Note from author: During the upcoming commissioning break both LHO and LLO (LIGO Livingston) will be installing an initial LIGO pre-mode cleaner at the beginning of the squeezed light path. We have sufficient evidence to support a theory that our squeezer control signals suffer from intensity noise. A mode cleaner will hopefully clean up any unwanted modes and noises above 160kHz.)

D: People thought something might be burnt (on the OMC).
N: Is that the main thing (purpose of the break)?
D: No. The baffle installation between HAM3 and HAM4 to reduce scattering noise is.

(Note from author: Scattering noise, as the name suggested, happens when some of the light scattered off from the main path to chamber walls for instance, gaining extra path length before recombining with the beam on the main path. These photons that have gained extra path length degrade the detectors' sensitivity as we rely on a precise measurement of phase difference between the beams travelling back from X and Y arm. HAMs are Horizontal Access Modules, a type of vacuum chamber containing optics in gravitational-wave detectors.)

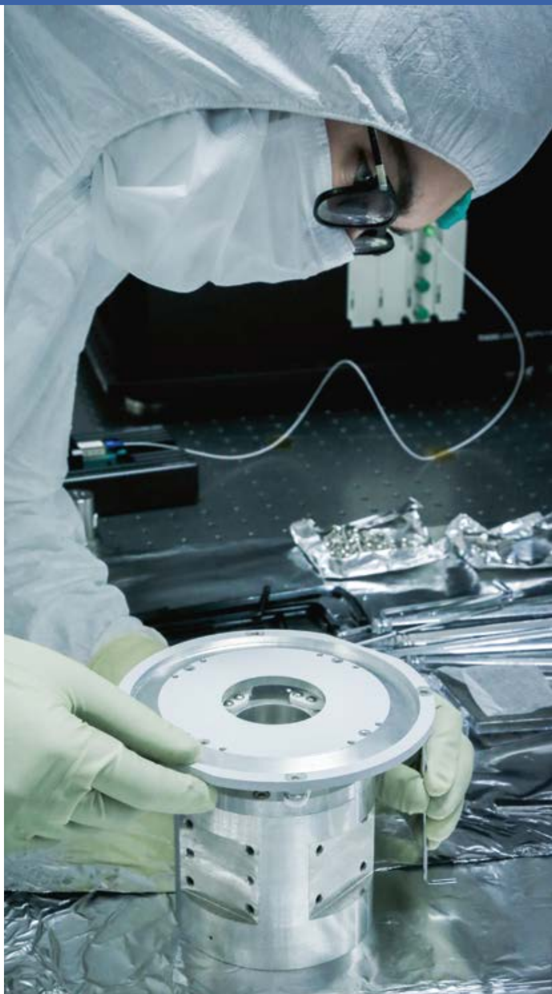
N: How did you guys figure out it was between HAM3 and HAM4?
D: You know. Robert. Kicking things.

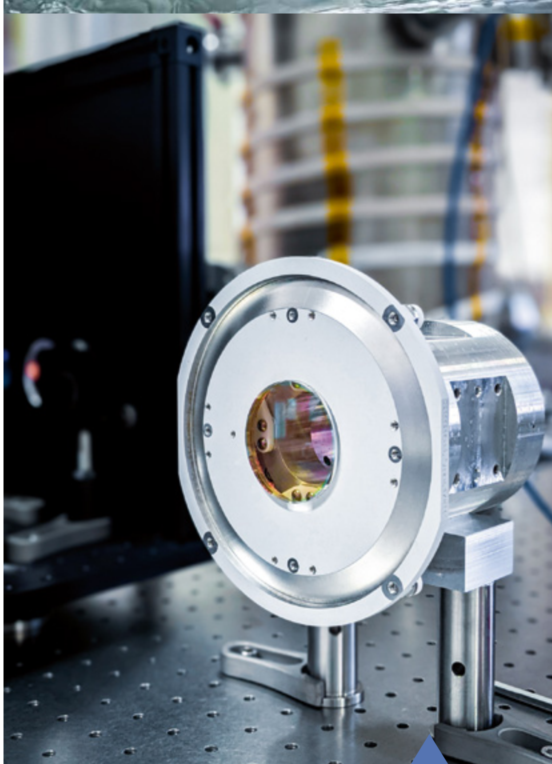
(Note from author: Robert Schofield, for those who don't know, is the LIGO environmental noise expert based at the University of Oregon. He injects environmental noise sources in a controlled way to understand how they affect the interferometer and figure out how much of those noises we can tolerate. Sometimes involved "kicking" things in a scientific way. Check out LHO alog37630[1] for the thirsty black ravens story for an example of Robert's (and co.) masterpiece.)

N: So what's LLO is doing?
D: Cleaning the test mass maybe.
N: I thought they didn't clean it because they were afraid of the First Contact[2] being left behind.
D: You probably know more than I do. (That is not true of course)

A few days after this conversation, additional HAM7 ZM4 ZM5 PSAMs range offloading has been added to the commissioning break schedule. PSAM stands for "Piezo electric suspended active matching stage" and is part of the adaptive optics system along with TSAMs (T for Thermal) that is located in HAM6. Both PSAMs and TSAMs allow us to change curvatures of the installed optics for mode matching purposes. Offloading the current setting to 0V would allow more range of voltage in either direction. To find out more about SAMS, check out the back cover article.

At the time of this writing the commissioning break is scheduled to start on January 16 and end on February 19 with an engineering run in between the commissioning break and the observing run. O4b is now due to start on April 1. Hopefully we don't detect anything too cool that day because no one is going to believe us!

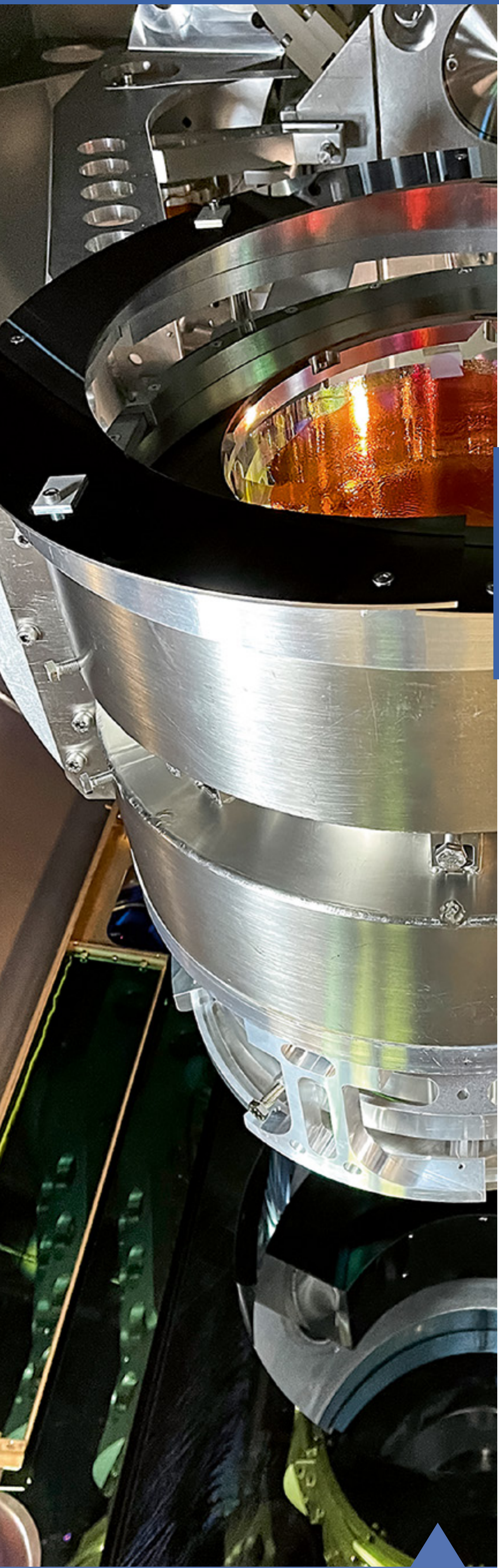




Top: *Thomas Roocke working on TSAMS assembly (see back cover).*
Below: *A T-SAMS.*

[1] LHO alog37630: https://alog.ligo-wa.caltech.edu/aLOG/index.php?callRep=37630

[2] First Contact is a brandname of a substance that we use to clean optics.



A s Virgo gears up to join Observing Run 4 (O4), in late January 2024 Deputy Editor-in-Chief Anna Green interviewed Virgo Spokesperson Gianluca Gemme to hear how things are going, and what plans are afoot for Virgo's future.

Gianluca Gemme

is Virgo's spokesperson. He's a boomer even if he doesn't know exactly what that means. Otherwise, he likes to spend as much time as possible outdoors, taking long walks, and trying to stay connected with reality.

Virgo's road to O4 ... and beyond

How is the mood at Virgo these days? When is Virgo joining O4, and with what sensitivity?

Virgo has faced challenges during the commissioning of O4, which have impacted the mood within the collaboration. Facing challenges is an integral part of enterprises at the frontier of science and technology, still the long commissioning period, constant difficulties, and disappointment of not starting O4 with LIGO imposed a toll that was visible on people's faces. However, there is some good news: the detector's sensitivity has improved, and the mood along with it. We have decided to enter the run at the beginning of O4b (the second part of O4) in March 2024. Our sensitivity is currently around 50 Mpc, and we will work until the last available day to do better. We are also preparing plans to overcome structural limitations that have been holding us back. Although there is still a lot of work to be done, we are optimistic about the future.

Take us back to summer 2023 - the decision was made to postpone joining O4. How did that come about?

In May 2023, Virgo's sensitivity was just over 25 Mpc. We considered entering O4, but it was clear that Virgo's contribution to network science under those conditions would be marginal, with the possible exception of rare events. We believed that we could do better and decided to take a few more months to continue commissioning and improve sensitivity. However, the decision not to join O4 was difficult and controversial. Virgo's mission is to take data and contribute to the science of gravitational waves, and not joining O4 was a manifestation of the failure of the planned upgrade program launched in 2019. It was a strong disappointment for us, for our partners and for our funding agencies. However, this shock has also been a stimulus to work even harder to improve both in view of O4 and to ensure the future scientific relevance of Virgo in the coming years.

Virgo's North End Mirror, which was replaced during the commissioning phase to reduce the level of noise in the detector.

What were the most challenging aspects of the commissioning and noise-hunting phases? Are there any remaining issues?

Commissioning of Virgo has been a complex process, and there are several factors that have contributed to the difficulties encountered. One of the main technical limitations is associated with the optical configuration of Virgo, which has marginally stable recycling cavities. Additionally, our limited ability to simulate the detector in this configuration has forced commissioning to proceed by trial and error, leading to errors and loss of time. We have also observed signs of aging in some subsystems that we have been able to mitigate to some extent, but which will require further action. Moreover, we are currently exploring ways to improve the organization and sharing of commissioning work across the collaboration which has shown some limitations. The interferometer is now operated with a circulating optical power at the level of Observing Run 2, and the best observing range is obtained using a trade-off between detector bandwidth and gain by reducing the level of signal recycling with a slight misalignment of the signal recycling mirror. The sensitivity around 100 Hz is limited by quantum noise, coating thermal noise, and an unmodeled noise with a weak frequency dependence, whose source is unknown and which currently represents the main obstacle to further improving sensitivity. We are working hard to reveal this unknown source of noise, while at the same time ensuring that we are ready to enter O4b with a stable and reliable detector.

What is the expected scientific impact of Virgo in O4?

Due to the growing sensitivity gap between Virgo and LIGO, Virgo's role in uncovering events will be marginal, but it will play a decisive role in localizing their origin in the sky. This has positive repercussions for external facilities that follow up our events, because the chances of achieving joint observations grows. In the case of exceptional events, such as GW170817, the presence of Virgo can make a significant difference and increase the scientific performance of the network in an extraordinary way, even though it has reduced sensitivity compared to LIGO.

Then, we must not forget the work done by Virgo members together with LIGO and KAGRA that will impact the expected science: many activities in various areas of the experiment are shared among the three collaborations and are made possible by everyone's contributions.

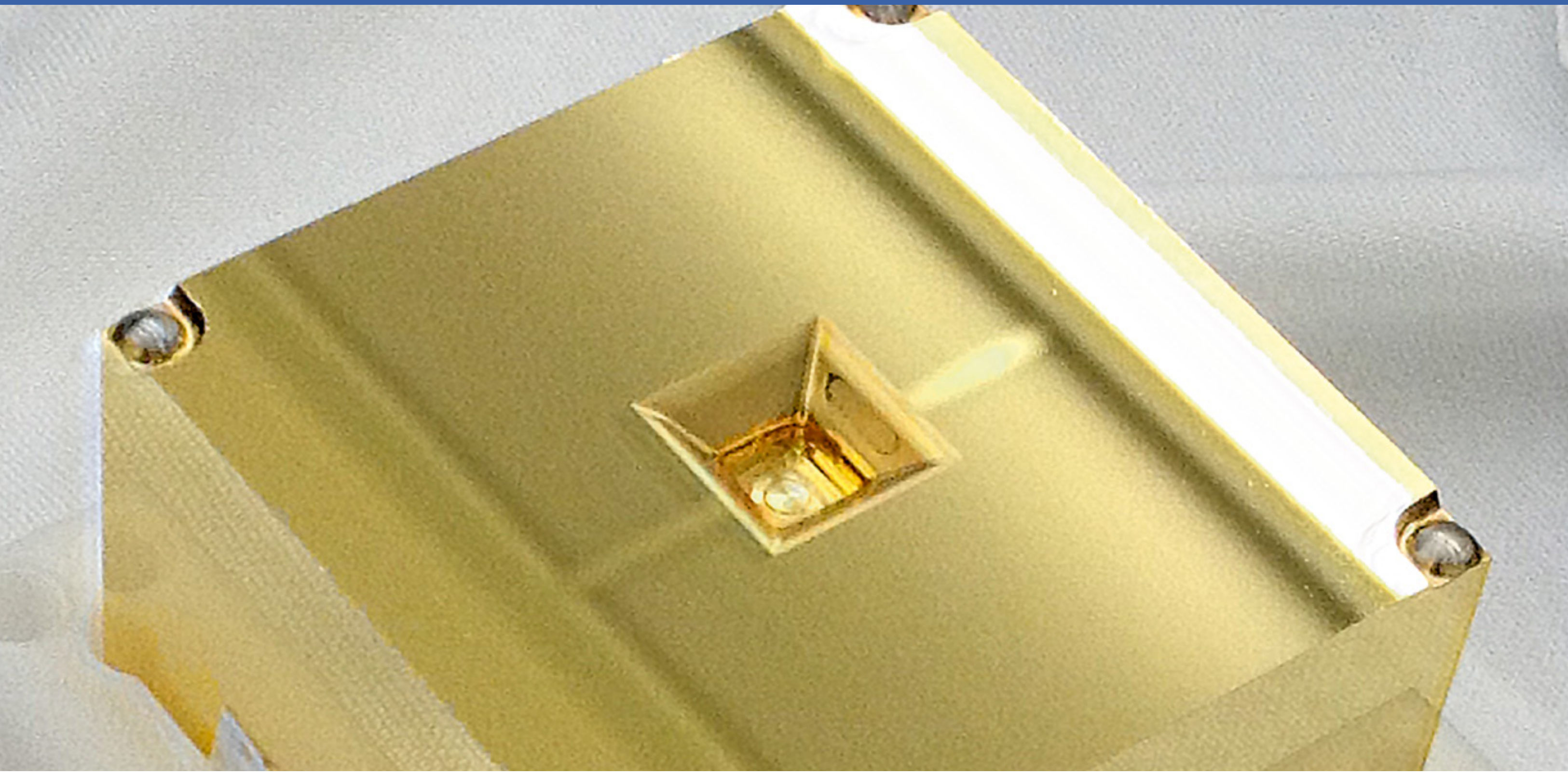
What are the plans for Virgo beyond O4?

The commissioning process for O4 has taught us some hard lessons, and it is necessary to address the causes that have made our lives difficult in recent months and limit our scientific potential. While it would be wrong to identify a single cause of our problems, the presence of marginally stable recycling cavities represents a strong limitation to the possibility of developing the scientific potential of Virgo in the medium and long term. We have been working since last May to prepare a plan for the installation of stable cavities for O5 and are working intensively to finalize it. We will soon decide on the optical configuration for stable cavities, and in the second half of 2024 we will have a solid project that will allow us to understand all the implications of this work. Timing is crucial for us to contribute to O5, and we will discuss with our partners, LIGO and KAGRA, the best strategy to maximize the scientific output of the network and ensure the scientific relevance of Virgo in the next few years. Additionally, we are working on a decadal development plan for Virgo in the post-O5 era. In this case, our goal is to present a plan to our funding agencies and the scientific community by the end of 2024.

With several new GW detector communities emerging, what lessons can be learned from Virgo, and what impact will these projects have on the existing detectors?

The Einstein Telescope (ET) is a great opportunity for European science, and I have been personally involved in the project since the preparation of the Design Study in 2008-2011. The attention of the scientific community and policy makers on ET demonstrates how gravitational wave research has taken on a very prominent role for fundamental physics and astronomy. However, the exponential growth of interest and activity related to ET in recent times has had an impact on Virgo. While it would be simplistic and self-absolutory to attribute Virgo's problems to ET, it is true that the tension between maintaining a consistent commitment to Virgo and actively participating in ET exists, particularly in some countries and in some groups of the collaboration. Our scientific community has grown significantly since 2017, but instrumental expertise needs time to be transmitted and is still in the hands of a relatively limited number of people and groups. I am less familiar with the situation of Cosmic Explorer in the United States, but I believe that coordination at the European level, as far as ET is concerned, and at the international level, as far as the network is concerned, would be beneficial to establish priorities and direct the available financial and human resources to avoid duplication of efforts and maximize the benefits for the scientific community at large. Also in this context, the more we learn and understand now in Virgo, the better we will anticipate and avoid problems in next generations of gravitational wave observatories.

more images on p.33



Nora Luetzgendorf

LISA gets go-ahead for implementation

is ESA's Lead Project Scientist for LISA and has been with the mission since 2020 where she started as LISA Study Scientist. In her freetime she enjoys horseback riding, dressing up as weird characters, and graphic design.

▲

In 2015, LISA Pathfinder tested important technology for the upcoming LISA mission. Central in the technology demonstration were two cubes of solid gold-platinum alloy. Each cube is a test mass with sides of 4.6 cm and weighing 1.96 kg. One of those cubes is pictured here.

The three spacecraft of the LISA mission will each host two of these test masses. They are free-floating and contained within an 'electrode housing'. Gravitational waves can be discovered when the distances between the cubes in different spacecraft changes. LISA will track these changes by exchanging laser beams between each pair of spacecraft.

In January 2024, Laser Interferometer Space Antenna (LISA) transitioned from the Study phase, where its feasibility and technology readiness were evaluated over the past three years, to the Project phase, when the actual implementation will start. In space terminology, this critical milestone is referred to as Adoption—an endorsement by the European Space Agency (ESA), its member states, and international partners signalling a consensus to proceed with and build the mission. The journey to this milestone, however, was not always easy.

Over the last approximately 30 years, LISA weathered numerous attempts, from the first thoughts of measuring gravitational waves in space in 1974 to the initial proposal to ESA in 1993 and the mission's reformulation in 2011. It wasn't until the resounding success of the LISA Pathfinder mission in 2015[1], demonstrating the feasibility of precise free-floating test masses in space, and the direct observation of gravitational waves by LIGO/VIRGO announced in 2016, that LISA experienced a new push forward. The successful 2017 proposal as ESA's new L3 (Large) mission by the LISA Consortium marked the beginning of a new era.

[1] Take a look back at LIGO Magazine issues 7 to 12 to find out more about LISA Pathfinder.

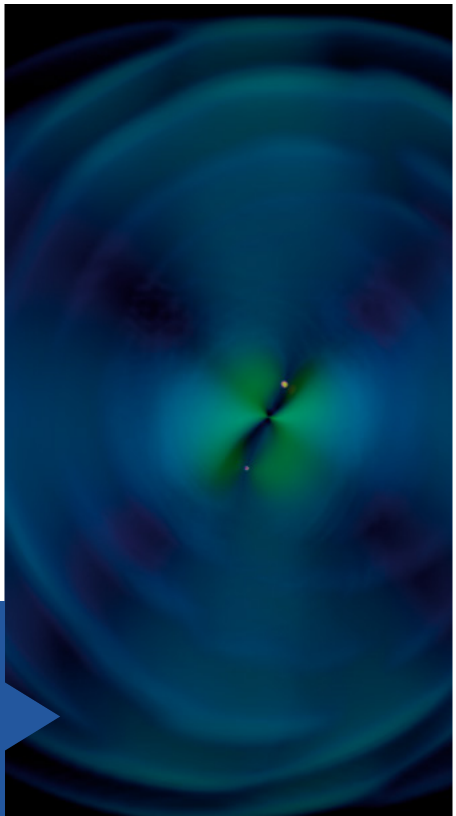
by Nora Luetzgendorf

All space missions follow roughly the same path, progressing from proposal to launch and post-operations. Each phase, labelled by letters and numbers, involves many assessments and refinements. Right after the accepted proposal, Phase 0 starts, which aims to assess if this mission is technically feasible and to identify the first requirements. For LISA, with such a long history and heritage from LISA Pathfinder, this phase lasted less than a year and concluded in December 2017. The subsequent phases, A and B1, involved further feasibility studies and refinement, with two prime contractors developing initial mission designs.

The conclusion of Phase B1 is marked by the Mission Adoption Review (MAR), a pivotal point where the mission designs from each of the competitive industrial studies undergo rigorous evaluation by ESA engineers. This phase is also when crucial contracts and documents are drafted, defining mission parameters and responsibilities. These include the Multi-lateral Agreement (MLA) outlining roles among ESA and member states, the Memorandum of Understanding (MoU) detailing contributions from ESA and NASA, and the Science Management Plan (SMP) containing data handling and release protocols, e.g. when and how often will the data be released to the public and how the LISA Science Team will be selected. This long approval process involves negotiations and meetings spanning several months.

The final significant document to highlight (there are numerous others, such as requirement documents and interface documents) is the Definition Study Report, also known as the Redbook. This comprehensive 150-page document summarizing the mission, is a crucial component. It undergoes evaluation by ESA science advisory committees, following which they advise the Director of Science on whether to proceed, or not, to mission adoption. Hence, the Redbook serves as the primary showcase for the LISA mission, requiring persuasiveness, conciseness, and consistency to convince committee scientists why LISA is an exceptional mission.

As one of the two LISA study scientists, my focus over the past 1.5 years was on coordinating the efforts of the LISA Science Study Team in crafting a compelling Redbook. Collaborating with 15 individuals across Europe and the United States, from various generations and backgrounds, posed challenges. For instance, when an entire chapter of the Redbook vanished overnight due to its deletion on Overleaf, it sparked a frantic 24-hour flurry of email exchanges, resulting in a few more gray hairs for everyone involved. Selecting the right collaborative platform, adhering to deadlines, and addressing technical and editorial issues required dedication. This effort was however dwarfed by the contributions of the LISA Science Study team and numerous scientists around the world who shaped the Redbook. The result, in my biased opinion, is a remarkable document that encapsulates the mission's beauty scientifically and technically, set to be a key reference for LISA. I feel very proud that I was part of the effort of to create this fantastic document.



Visualisation of gravitational waves from a binary black hole merger. The two black hoes are shown in the centre and the emiited gravitational wave is shown in blue.

What comes next for LISA after adoption? We're now moving into Phase B2, where we'll choose one of the two main contractors and officially begin implementing the mission. This marks the start of the development phase, bringing the mission one step closer to reality. Everyone is clear about their roles and can focus on their specific tasks.

On the scientific side, we'll establish a new LISA Science Team tasked with advising ESA on all aspects related to the scientific outcomes of the mission. This team, co-chaired with the NASA Project Scientist, will be assembled through an open joint call, allowing anyone working in an ESA member state or the US who is interested in contributing to the mission to apply. The coming years will be packed with activities for the science team, from defining initial science cases to finding strategies for creating final catalogues and engaging the broader scientific community. It's going to be an exciting journey with LISA!

Read the LISA Redbook at: www.cosmos.esa.int/web/lisa/lisa-redbook.

The Tactile Universe – a unique collaboration

A 3D printed tactile surface showing the inspiral of two black holes and the resulting gravitational waves that the system will produce.

The Tactile Universe project has been working in collaboration with several gravitational wave research groups across the UK to develop educational workshops using tactile and audio resources designed to be accessible to blind and vision impaired people. The resources are available to download and 3D print for free, and we'd love to share them with you.

Nic Bonne

is a Public Engagement and Outreach Fellow at the University of Portsmouth's Institute of Cosmology and Gravitation where he leads the Tactile Universe public engagement project. In his free time, he likes to play the bass guitar and is frequently taken on long walks by his guide dog Austin.

I'm Dr Nic Bonne, the vision impaired astronomer and science communicator who leads the multi-award winning Tactile Universe public engagement project. Based at the University of Portsmouth in the UK, since 2016 we've been developing tools and resources to provide blind and vision impaired people, particularly students, alternative ways to access topics in astrophysics research. By doing this, we hope to raise the aspirations of these students, and show them that science can be for them, even if they may have to approach things in slightly less traditional ways.

One of the biggest issues faced by blind and vision impaired people when it comes to engaging with astronomy is the very visual nature of the field. Everything from how we do our research (a reliance on data as images and communicating results through visually complex plots), to how we teach and inspire the public (often with beautiful false colour images of space). Even the descriptions and analogies we rely on can often be overly visual.

Given these barriers to access, being blind and a professional astronomer is obviously an unusual combination. I've had a severe vision impairment from birth, but this didn't stop me from being fascinated by all things space from a young age. Chasing my dream of one day becoming an astronomer wasn't always straightforward and it often required a lot of extra work (and some unusual problem solving) to access what I needed to learn about the subject. I was also quite lucky that a number of my educators (in school as well as at University) were willing to spend the time to work with me to develop more accessible solutions. Despite this, we did often find ourselves making things up as we went along because the accessible resources we wanted or needed just didn't exist.

The Tactile Universe project started in 2016 shortly after I completed my PhD and had moved to the UK to start my first postdoc. I'd begun to develop an interest in outreach and public engagement work and my line manager Dr Karen Masters asked me "What would have made your PhD research easier for you to do?". Because my research focus had been on galaxies and their morphologies and colours, my instant response was "To make my galaxy images tactile!". My colleague Dr Coleman Krawczyk, who's now the project's technical lead, overheard this and decided to create a plug-in for 3D modelling software Blender that would create images like the ones I'd described. Coleman's plug-in creates digital 'height-maps' of images where the height scales with the brightness of an image's pixels. By 3D printing these surfaces, users can feel how the brightness changes across an image of a galaxy and feel the shape of that galaxy without the need to look at the original image. When I got hands on with our first 3D printed prototype (an image of Messier 51, the Whirlpool galaxy) we realised that we'd created something really unique that other people would probably find interesting as well.

With the help of Karen, Coleman, and Dr Jen Gupta (our department's outreach and public engagement manager), we worked with our local blind and vision impaired community to refine these models (to find the best size, tactile height etc) and to settle on the best language to use when describing them. As the project began to grow in scope and reach across the UK, we realised very quickly that we were going to have the biggest impact if we focused our efforts on working with blind and vision impaired students specifically.

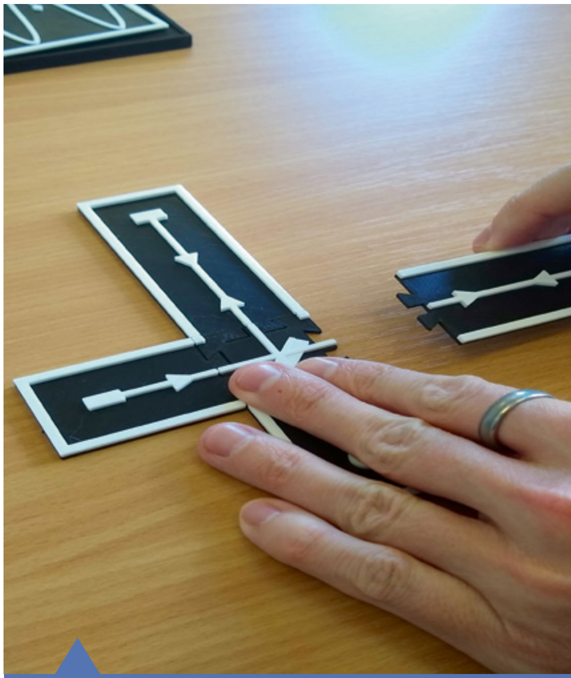
Over the last several years, we've developed and shared accessible resources and workshops focusing on the solar system and galaxies, and have worked in classroom settings to inspire and encourage students to think differently about how they engage with science topics like astronomy. Many of the vision impaired students in the UK are embedded in mainstream classrooms, so by including everybody in these classrooms, regardless of how much they can see, and encouraging everybody to use our tactile resources together, students have reported feeling more engaged and included. We've also found that students have the most powerful and rewarding experiences when they are allowed to explore our tactile models and discover interesting features without being guided too heavily. Their questions can then guide the discussion around the resources.

In 2020, with joint funding from the UK's Science and Technology Facilities Council and the University of Portsmouth, the Tactile Universe set out to develop new tactile resources to pair with existing audio resources that would allow us and other experts to communicate topics around gravitational wave research in more accessible ways. The choice to focus on gravitational waves was an easy one. The gravitational wave research community is unusual in that, from the very first direct detection of gravitational waves in 2015, there has been a willingness to communicate results in less traditional and multimodal ways. I'm of course referring to the audio 'chirps' released alongside many of the major gravitational wave event detections.

What have we created?

Once again, throughout the process of designing these new resources and workshops, it was important to work with gravitational wave researchers (in particular Dr Laura Nuttall from Portsmouth and Dr Chris North from Cardiff) to make sure our science was on point. Even more importantly, we once again worked closely with local specialist teachers and blind and vision impaired school students to get as much input on what we were developing as possible.

Through this consultation, we've developed three short educational workshops appropriate for students in upper secondary school and older, covering: (1) Compact objects, (2) Common sources of detectable gravitational waves, and (3) Gravitational wave detectors. Each workshop lasts for roughly 20 minutes (with some extra time for student questions) and is structured like a conversation with frequent opportunities for students to ask questions, discuss ideas or highlight any concepts that might not make sense. We've also tried to reinforce core physics concepts from standard school curriculum (like gravity and waves) to help students build up the background knowledge they need to understand the workshop content. Unlike our previous workshops, these are designed to work best for smaller groups of students.



A tactile puzzle-piece interferometer that is used to talk about how gravitational wave detectors like LIGO work.

In the first workshop, we discuss mass, density and gravity, and introduce students to compact objects (like black holes and neutron stars). We use simple props, identically sized ping pong balls, squash balls and a ball bearing (each a factor of 10 heavier than the last) to talk about mass and density. We also have simple 3D printed tactile diagrams of orbits, and a table-top version of a stretchy space-time demo built using embroidery hoops, stretchy fabric, popsicle sticks and 3D printed brackets that we can use to talk about how mass distorts spacetime.

For the second workshop, we discuss waves and the compact binary systems that produce detectable gravitational waves. Dr Simone Mozzon, one of our gravitational wave research group's past PhD students, used modified code shared with us by collaborators from the Max Planck Institute for Gravitational Physics and the Simulating eXtreme Spacetimes (SXS) collaboration to produce a series of snapshots of the inspiral and merger of a black hole – black hole binary system. We then converted these images into tactile surfaces. By feeling these snapshots in sequence, students can get an idea of how a compact binary system evolves over time and how the gravitational waves produced by the system will change as the system evolves. We pair these models with examples of audio chirps from different types of binary inspirals to demonstrate how the properties of these systems can change the parameters of the detected gravitational wave signal.

In the third workshop, we focus on interferometers like LIGO, explain how they can detect gravitational waves on Earth and why this is so difficult. To supplement this, we've developed a tactile puzzle piece interferometer diagram that students can put together as we describe how the laser light moves through a detector. We also use audio chirps with noisy backgrounds (sourced from Black Hole Hunter) to discuss the many sources of noise that need to be considered and accounted for.

What's next?

With development and testing of our resources and workshops completed in late 2023, the core project team and some of our gravitational wave researchers travelled to the University of Glasgow, Cardiff University and the University of Birmingham to train their respective gravitational wave research groups in how to use and deliver our resources. We left a full physical resource kit with each group, and we're now coordinating with them so they can start to connect with local schools and students. We'll also use their feedback and the feedback of the students and teachers they work with to continue to improve our resources and how they are delivered.

We'd love to share our resources more widely with any other gravitational wave researchers, science communicators or educators who might be interested in using them. All of the 3D printable resources, 3D printing guides and lesson scripts are currently available for free to download on our website (www.tactileuniverse.org). We'd love to hear from you and help to support you if you're interested in using anything we've developed. We can be contacted by email at tactileuniverse@gmail.com.

A 3D printed tactile image of galaxy Messier 51. The tactile features in the image trace the brightness in the original image, allowing users to 'feel' the shape of a galaxy.

Interview with Victoria Grinberg

Victoria Grinberg is a liaison scientist with the European Space Agency. In her research, she uses X-ray binaries – systems consisting of a compact object accreting material from a companion star – to study stellar winds in massive stars and accretion/ejection processes onto black holes and neutron stars. In her free time, she tries to find ways to make her field more sustainable – also as part of Astronomers for Planet Earth.

Welcome to Climate Change Conversations, a new article series exploring climate topics. In the first of this series, Quynh Lan Nguyen and Luca Baiotti, members of the LIGO-Virgo-KAGRA (LVK) Committee on Climate Change, interview Victoria Grinberg. We discuss Astronomers for Planet Earth, explore the role of collaborations in tackling climate change, and talk about how all scientists can contribute to climate communication.

You are one of the founders of Astronomers for Planet Earth – what is it and how did it come to be?

Astronomers for Planet Earth (A4E, https://astronomersforplanet.earth/) is a grassroots movement in astronomy. The idea is to unite astronomers (including astronomy students, educators, amateurs and scientists) working globally in order to address climate change with our special perspective. A4E members have organized conference sessions and full (remote) workshops, made videos, written papers, contributed to CO2 assessment of their institutes, done all kinds of outreach from talks to organizing whole concerts or environmental hikes, founded local sustainability working groups and much more! It really depends on what individual people or groups are able to do in their corner of the world and science.

The Europe-based part of the movement started in 2019, at the EWASS[1] conference, the largest astrophysics conference in Europe, in Lyon. We were in the middle of what, at this point, was the worst heat wave that France had ever experienced. This meant that sessions had been moved to early mornings to avoid the midday heat, but the temperatures at the meeting venue were still unbearable. The organizers managed to get some fans but they hardly helped. Everyone was miserable. Some of us complained on social media about the heat. The conversation quickly turned into a discussion on whether the climate impact of our travel was part of the problem as many of us got to Lyon by plane. We later looked deeper into the climate impact of this particular conference [1]. We also realized that to change something we would need a way to connect to others, so the idea of a yet-unnamed sustainability network in astronomy and astrophysics was born. We then learned that some colleagues in the USA had the same idea and since they had already established a name, we decided

[1] European Week of Astronomy and Space Science. The conference has since been renamed to EAS (European Astronomical Society).

to continue using it. Since then, A4E has grown to a world-wide network with nearly 2000 members from 76 countries as of January 2024.

How can people get involved in Astronomers for Planet Earth?

The best way is to become a member on our website and then join our Slack where people suggest and discuss different projects!

What is the role of collaborations like LIGO-Virgo-KAGRA (LVK) in addressing climate change?

Oh, a giant one! Decisions by individuals do have impact, but it's limited by the system. Large collaborations have the chance to change the system. As a simple example: an individual may decide not to fly to conferences, but if all meetings in their field are in person, this will have a negative impact on their career. If a collaboration like the LVK decides to move some or all meetings online, it makes them both more accessible and more sustainable [2]. The collaboration may also decide to switch to renewable energies for their data systems. Or do a full environmental assessment of their experiment before building it to minimize the environmental impact.

All of these possibilities work in two ways: first directly, by either enabling its members to be scientists in a more sustainable way without disadvantaging their careers or by being more sustainable as a group. Secondly by being an example, both within the (astro)physics community and outside of it.

Of course even large collaborations are still often limited in what they can do, for example through the rules of their funding sources. However, they have a lot more impact when it comes to trying to change these rules.

Large science efforts (like the LVK) are collaborative endeavors. Conferences are often excellent opportunities for junior people to meet and gain visibility. How can collaborations decide which meetings are best in person and which to hold online?

This is an excellent question – when I give talks about academic travel, I will often ask my audience to think about what it is that makes them go to conferences. Most people say that it's all about networking, about meeting new colleagues and reconnecting with old collaborators. I guess most of us have also, at some point in our career, heard someone say that the most important session of the conference is the coffee break.

The problem is that most conferences hardly offer any chance to actually connect. If you spend 7 or 8 hours listening to talks, there is little time and energy left for scientific discussions, to develop new ideas and start new collaborations.

In short, the world and the way we do science has moved on but we are still running conferences in the same way we did decades or maybe even a hundred years ago!

I'm convinced it's worth re-thinking meetings in general with a focus on what the aim of a meeting is: if it's to convey information or advertise results through talks, it can be fully remote or, to enable some local discussion, based in local hubs (see e.g. [3]) distributed all over the world. If it's an unconference, i.e. a participant-driven meeting, or a workshop that maximizes in person interaction and networking, in person or hybrid will be better. But to travel half way around the world to sit in a stuffy room, in an uncomfortable chair and listen to talks is not just unsustainable, it frankly feels more and more like a waste of my time (even though I know that a classical conference is much easier to organize than something like an unconference workshop!)

Are there examples of collaborations leading the way on these issues, and what are they doing?

Absolutely! One example is the X-IFU[2] consortium, who have looked into the travel footprint associated with the development of their instrument and have taken steps to minimize it [4], including reducing the frequency of consortium-wide meetings and replacing many of the working meetings with video conferences. They have also produced a great travel footprint calculator [5] that can be used to find a location for a meeting that would minimize the travel footprint.

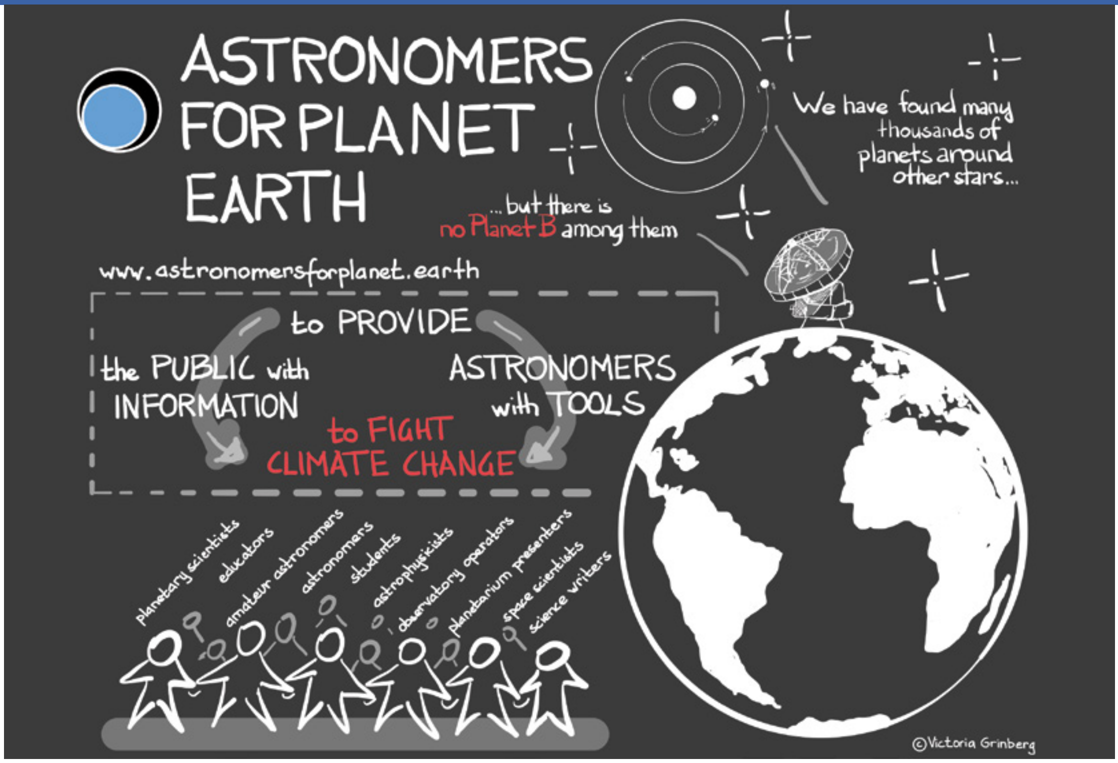
Another is the the Giant Array for Neutrino Detection (GRAND), who have estimated the carbon footprint of the different phases of their project [6] and have done the full life-cycle assessment of their prototype detection units [7] in order to develop recommendations that would enable them to reduce the environmental impact of the project at later stages.

There is also the energy consumption and carbon footprint estimate for the LOFAR (Low Frequency Array) telescope [8] and many more! And those are only the ones that resulted in papers that I know of!

How can we use our work to communicate climate science?

There is a great, short paper in Nature astronomy on this [9], written by Prof. Alison Anderson, a sociologist who specialises in climate communication. It is based on a talk she gave at a European

[2] The X-ray Integral Field Unit, an instrument for the Athena ESA mission



▲ *Find out more at www.astronomersforplanet.earth*

Astronomical Society conference session on sustainability that A4E organized. This paper points out that astronomers are trusted voices in communicating science and can encourage the public to listen to climate experts. I think the same applies to physics, especially gravitational-wave physics. The paper also discusses some simple approaches on how to do so – by telling stories, making it relevant to the audience and focussing on solutions.

Whenever we do outreach, we have the chance to reach people who are willing to listen to us – but may not listen to a climate scientist! We can also include climate science in our lectures, especially broader, introductory lectures. Of course we also need to be conscious of the environmental impact of our own work – and do so openly, talking to others in our field about it.

How can we create a balance between generating scientific results efficiently and quickly, and minimizing the environmental impact of our collaboration?

There is no single recipe on how to go about it, but in the end, it is about finding the right balance and future-proofing our own field. What sense does my science make if there is no humanity in the future to appreciate the new understanding of the universe we achieved? How can we plan for experiments over the next 20 years if we are, at the same time, in danger of environmental collapse, which would make new science impossible since we'll have to focus on survival?

For me, the guiding question is what do we need to do to be able to continue doing great science in, say, 50 years. And as you certainly know in the LVK collaboration, this is not an unrealistic timeline for big physics experiments.

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The Business End of Big Science Ops

Top row (left-to-right): *Nichole Washington; Christina Carrasco and Liz Natividad; Dolly Richards, Eadie Balint, and Kim Burtnyk.*

Middle row (left-to-right): *Hannah Hansen; Jason Drobish; Marie Woods; Pricilla Godbey.*

Group photo: *Eight members of the LIGO Business Office during a recent trip to Caltech.*
Back row, from left: *Dolly Richards, Jamie Goad, Hunter Roman.*
Back row, from right: *Melanie McCandless and Carolyn Peterson.*
Front row, from left: *Elizabeth Natividad, Nately Sych, Lorna Campbell.*
Others in the photo are LIGO staff members Madeline Lesovsky (back row), Melody Araya, and Melina Fuentes-Garcia (front right).

LIGO's success doesn't happen in a vacuum. Well, okay, some of it does, but metaphorically, there's so much more to LIGO than lasers and mirrors and sensors. While the outside world marvels at LIGO's discoveries, it's probably fair to say that few people outside of LIGO Lab ever think about the business side of the whole adventure. Standing behind the discoveries, beyond the engineering labs at Caltech and MIT, beyond the computing infrastructure and detector hardware large and small is a dedicated group of business professionals supporting the entire enterprise.

Without a business office managing LIGO's annual $50M budget, we couldn't operate the observatories. Led by the Chief Operations Officer, Hannah Hansen, the LIGO Business Office serves multiple functions within the LIGO Laboratory, from site administration, to grants management and accounting, purchasing, shipping, and inventorying Lab equipment and supplies, travel arrangements, NSF (National Science Foundation) reporting and so much more.

Now, for the first time, peek behind the Big Science curtain to meet the LIGO Business Office and learn how we help LIGO succeed in its scientific mission.

Site Administration: The friendly faces at LIGO's front doors

by Nately Sych (Caltech), Marie Woods (MIT), Pricilla Godbey (LLO), and Eadie Balint (LHO)

The LIGO Laboratory spans four locations across the United States: Caltech (California), MIT (Massachusetts), LIGO Livingston Observatory (LLO) in Louisiana, and LIGO Hanford Observatory (LHO) in Washington State. Of course, this means that LIGO's employees are also spread out, so who takes care of the daily administrative needs of faculty, engineers, staff, students, postdocs, fellows, and official visitors? LIGO's site administrators!

Located at each LIGO Lab site, we wear the most diverse hats in the Business Office, orchestrating a dizzying array of tasks ranging from supporting the LIGO Directorate's office to managing LIGO's Visitors and Fellows programs; onboarding employees, undergraduate interns, graduate students, and postdocs; organizing on- and off-site meetings and events; assisting faculty and staff with completing expense reports; answering site-specific questions; keeping track of who's on-site and who's out, and a whole lot more. In short, we make sure that the 190+ people working for the LIGO Laboratory at any given moment have all the administrative support they could possibly need at all times. No small feat!

Travel Coordination: Around the world and back again

by Eadie Balint

Given LIGO's global collaboration, LIGO staff, postdocs, and graduate students travel both domestically and internationally. And since LIGO is funded with U.S. taxpayer dollars, all such travel must follow strict Federal government rules. Understanding, navigating, and adhering to these often complex and frequently changing rules is the responsibility of LIGO's Travel Coordinator, a role I play in addition to my duties as LHO Site Admin.

How necessary is this role? In 2023 alone, I helped arrange over 200 trips between LIGO and LIGO Scientific Collaboration (LSC) institutions, to LIGO-Virgo-KAGRA meetings, conferences, the annual NSF LIGO review, and other LSC-related activities around the world!

With all the rules that need to be followed, booking complex international or domestic travel can be burdensome. As LIGO's Travel Coordinator, I help to ease that burden, ensuring that traveling staff can focus 100% on the reasons for their trip without worrying about the logistics.

Grants Management: LIGO's budgeting and reporting experts

by Jamie Goad and Jason Drobish

Ever wondered how much money, time, and resources it costs to build and improve upon LIGO? Try about $50M per year, including funds from the 5-year LIGO "Operations award" from the NSF, and an additional 29 (and counting!) smaller grants and awards. These funds are distributed among multiple groups within LIGO, with budget managers responsible for spending their piece of the pie in support of LIGO's mission. But keeping close tabs on budget managers and the whole $50M+ is the job of a two-person LIGO Grants Management Team.

Every day, we provide financial expertise and budgetary advice in an ever-expanding organization and Universe. Monitoring nearly 30 budgets requires ensuring that managers have adequate funds to purchase what they need, and advising on other courses of action when a budget gets thrown a curveball, like if a critical piece of equipment originally thought to cost one amount ends up costing a lot more! Federal awards, like LIGO's, also come with lots of rules, so we are responsible for ensuring that the Lab complies with all purchasing, travel, and documentation requirements and adheres to all guidelines defined by the conditions of the award sponsor.

LIGO Grants Management also coordinates with Caltech's Office of Sponsored Research and the Division of Physics, Math, and Astronomy to support LIGO Lab-wide funding proposal efforts. Such proposal development is especially paramount to LIGO continuing to receive Operations funding from the NSF every five years. Taking nearly a full year, this highly intricate planning and review process requires the coordination of dozens of professionals across multiple institutions.

Although it may seem like it to some, overseeing $50M isn't magic, but is a bit more than just accounting. The whole process can sometimes feel like assembling a complex machine, but that complexity is paid off in the end when a budget can run like a well-oiled (and properly funded) machine. And getting it all to balance out exactly to the penny is pretty cool, too!

In the end, one of the most rewarding aspects of Grants Management is collaborating with supervisors and budget managers to help them make informed, confident financial decisions, so they can get back to science!

Procurement: One-stop shop for LIGO's purchasing needs

by Dolly Richards, Carolyn Peterson, Melanie McCandless, and Hunter Roman

LIGO's Procurement team helps LIGO Lab purchase all the equipment we need to fulfill our scientific mission. In 2023, our small group of three purchasing agents and one intern oversaw 1,886 purchase orders totaling over $8.5M! Talk about retail therapy!

LIGO's success doesn't happen in a vacuum

A highly rewarding part of our job is providing guidance and assistance to everyone at LIGO to help them acquire the goods and services they need. Often, our teammates on the technical side aren't sure where to start, or exactly what is required when initiating a procurement, so we assist them through the process. This includes helping to develop well thought-out and detailed statements of work (SOW) describing what is needed and identifying potential suppliers of often highly-specialized equipment; issuing requests for proposals, inviting potential suppliers to bid on providing the needed equipment or service; facilitating the review and evaluation of such proposals; selecting the 'winning' supplier; and ultimately ensuring that items have been received and all invoices have been processed.

In addition to everyday purchases, we also plan and execute long-term procurements–things like construction contracts–and report status or progress updates to the NSF and others in the LIGO Business Office. One ongoing long-term procurement success story is the multi-million dollar facility upgrade to our Advanced LIGO observatories, known as A+. For this project (slated for completion in 2025), we bought everything from nuts and bolts, to vacuum beam tubes, to the construction materials required to build an addition to our existing facility that can offer five times the gravitational wave event detection rate over the previous Advanced LIGO design.

The procurement team is also required to have an excellent working knowledge of the regulations surrounding spending government funds. This means ensuring that each and every purchase is properly documented in accordance with our funding-source agreements. Documentation varies depending on the cost of the item(s) being purchased, but can include obtaining certifications from suppliers (verifying that they comply with Federal rules) or sending the SOW and proposal to the NSF for review and approval. It also means that we develop, update, train, and communicate processes and procedures to the Lab.

◀ In 2023, LIGO's Property and Logistics team moved a 11,500 lb HAM chamber from LLO to Caltech. Every detail was carefully planned, from the chamber's removal, to placing it on the trailer, wrapping it for transport, shipping it 1800 miles, and receiving it at Caltech 14 days later. The complex and delicate operation involved 20 LIGO staff members.

Property and Logistics: LIGO's backstage crew

by Nichole Washington, Elizabeth Natividad, Christina Carrasco, and Val Hincks

Step into the realm of LIGO Property and Logistics (P&L), where our team assumes a vital role in the seamless orchestration of all property and logistics activities across the LIGO laboratory. P&L shoulders the responsibility of reviewing all equipment acquisitions and managing Caltech and government-owned assets from cradle to grave. Our daily operations encompass property inspection, identification, disposal, and records management. In collaboration with key LIGO groups like Facilities and Systems Engineering, P&L excels in handling, shipping, and receiving unique fabricated parts and equipment. We receive and efficiently process all incoming shipments, ensuring timely delivery across the lab.

Additionally, we specialize in carefully packaging all outgoing shipments, guaranteeing safe and secure transport to their destinations. One incredibly unique and exciting logistical task occurred in 2023 when we orchestrated the transport of an 11500 lb vacuum chamber from LLO to Caltech!

Recognized as the go-to team, the P&L group extends its expertise to efficient storage organization, skillful forklift and crane operation, and replenishing office and lab supplies. We respond to unique requests, offering services such as technical cleaning, clean and bake assistance (a process whereby anything installed in LIGO's vacuum envelope is removed of contaminants), and assisting with assembling interferometer components in cleanrooms. But our team's commitment goes beyond day-to-day operations: we also coordinate, conduct, and report internal property audits, while facilitating external audits to comply with government property management requirements.

In essence, P&L is the backstage crew, methodically handling logistics and ensuring every service request is skillfully handled. We are dedicated to supporting the triumph of LIGO's scientific pursuits, enabling our colleagues to focus on pushing the boundaries of knowledge.

Reporting and Editorial: Effective communication

by Kimberly Burtnyk-Moraru

Just as there are strict government rules for managing funds and acquisitions, rules also exist for reporting how we use those funds. Each year, LIGO is required to submit multiple reports to the NSF detailing how our budget is actually spent on R&D, science, engineering, equipment and supplies, maintenance, outreach, and other tasks. Moreover, without timely completion of these reports, NSF could withhold our funding.

Generating these reports is my primary responsibility as the LIGO Laboratory Technical Editor. Throughout the year, I collaborate with about 25 LIGO managers to assemble and edit an Annual Work Plan detailing hundreds of scheduled tasks for the year; quarterly reports revealing LIGO's progress towards its goals; and an Annual Report describing what we accomplished. In the process, I get to see what everyone is working on across the Lab!

If "Reporting" is all serious, then "Editorial" is all fun! In between report-writing, I update and generate content for the LIGO Lab website, helping to explain what we do to the average human being. And throughout the year, I'm LIGO's in-house editor, proofreading, formating, or editing anything from multi-million-dollar grant proposals to memos. Efforts here range from typo-hunting (one–mortifyingly inappropriate to share–was a real word, one letter less than the intended word, but lightyears away from the intended word!) to working one-on-one with colleagues on their writing projects. Writing is very personal to most people and the thought of being edited can be anxiety provoking; as a writer, myself, I know how that feels. So I am always humbled when someone trusts me with their precious words.

In my dynamic and stimulating role, I am constantly learning new things while supporting the LIGO Lab's communication efforts. It truly is an honor to work alongside such exceptional people, and play my small role in LIGO's success.

Staff Relations Manager:LIGO's human resources connection with Caltech

by Lorna Campbell

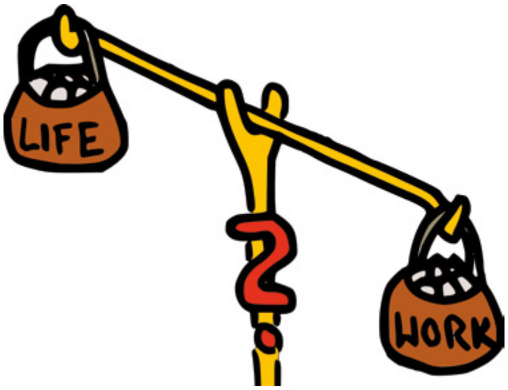
While most LIGO Lab staff are Caltech employees and have access to Caltech HR services, LIGO Lab also employs a Staff Relations Manager to support its people. In this role, I am a dedicated human resources professional tasked with supporting staff, overseeing hiring, leading diversity, equity and inclusion efforts, and recruiting new staff. The job suits me perfectly. I love helping people, I always have, and ultimately that's what my role allows me to do every day.

Since joining LIGO Lab in 2021, I've participated in all hiring committees, providing oversight to ensure our hiring practices are fair, legal, and equitable. My position also serves as the key first point of contact for questions our staff have about employee benefits, immigration issues, or problems, concerns or questions about life as a LIGO employee. In general, the Staff Relations Manager is a safe, confidential, first port-of-call for any staff member with a worry, issue, or question.
I am also the co-chair of the Inclusion, Diversity, Equity and Access (IDEA) Committee, and lead many of the labs efforts in this area, including creating internships, implementing equitable hiring practices, providing training on biases and other barriers to diverse hiring, surveying the staff to establish areas of improvement for LIGO Lab as an employer, and providing monthly DEI (Diversity, Equity, and Inclusion) training through the LIGO Lab Ripple Effect education series.

Unity in Diversity

LIGO's business office is a diverse group of individuals with a wide set of backgrounds and experiences. We're also a fun bunch that strives to not only support each other, but also everyone in the lab. To some, what we do may sound unglamorous or even boring compared to LIGO's exciting scientific endeavors, but we all love what we do, and most of all, we are privileged to be integral members of the LIGO family.

Work-life balance: Parenting in Academia



As we are all aware, work-life balance in academia, and particularly in large collaborations like the LVK, can be very challenging. Frequent travel, or even jobs split between different cities or countries, are not uncommon. By the time we get our first permanent position and our lives reach a level of stability, we are often already quite 'old'. All of this can be very disruptive for our social lives, relationships and families. So how do children fit into the life of a scientist in the LVK? Almost 60 of you replied to our recent survey, including many detailed insights. Your willingness to share your thoughts and experiences suggests that this topic is usually underrepresented in our discussions. While it's impossible to comprehensively address such a complex topic in a short article, we want to highlight several aspects and show different perspectives.

Usually children are associated with a negative impact on their parents' careers. Less than 10% of our respondents characterized the overall impact as "positive". On one hand, many noted a reduction in working hours, high added mental load, and travel issues. Michalis Agathos writes: "Apart from the impact on mental state (sleep deprivation, fatigue) and cognitive load (unbelievable amount of extra responsibilities), there was direct impact on the amount of work I can carry out beyond the weekday 9-5 work schedule, which we academics tend to consider as a given. [...] Traveling has reduced to the bare minimum for conferences and to zero for research visits. Frequent illnesses meant that every other week I'd have to stay behind with tasks and my backlog only got longer."

On the other hand, many note that the quality of research comes not just from the hours put in, but from a general life satisfaction - "happiness and feeling of fulfillment in life", as one person put it.

Frank Ohme writes: "Both positive and negative aspects [...] are absolutely true. However, having children undoubtedly made my life better, and made me better know myself. So, I think the positives outweigh the negatives even if we focus only on work style. Among the best things I learn from my children are: patience, understanding the perspectives of others, dealing with emotions, setting priorities". This is a sentiment shared by many: 20% of respondents felt that parenting had a

Jessica Steinlechner

I am an associate professor at Maastricht University. I had my first son (now 14) during my PhD, when I lived in a country with good, affordable child care and good parental leave conditions for both parents. My second son was born three years later, just after finishing my PhD and before moving abroad for my first postdoc. The experience with the first child was very helpful for daring this 'adventurous' timing for child two. Back then, and still in retrospect, this was the best possible timing, as later on, the job only ever got more intense.

Mikhail Korobko

I'm a staff scientist at the University of Hamburg in Germany. I got my kids (now 7 and 4) in my second and fifth year of PhD. We decided to get kids early when I still had several years of stability before postdoc ahead and lots of energy to work and parent efficiently. For me that was the best timing: now I have so much more academic load, that even though I have a permanent position, having young kids would've been even more stressful. It also taught me patience and multitasking, which comes very handy now.

positive impact on their working style. Laura Nuttall goes into more detail: "I have had to become so much more efficient in what I do in order to fit it into the time I have. It comes with a lot more stress, but I have removed a lot from my diary or passed on things to other people [...] Therefore my work is really all about the things I really like doing and what I am responsible for."

So, how does parenting affect one's career path? Pregnancy and postpartum time often bring physical and psychological challenges that may impact working capacity. This can significantly interfere with academic career timelines. For many, every decision was a compromise: "I have to consistently make choices of whether I am neglecting my work or my children", writes one respondent. Another ended up dropping out of a PhD program due to the high load from both the research and the children. Others note that parenting positively impacts career "indirectly through positively impacting ... life", as Joey Shapiro Key put it.

Given all this, is there the best time to have children? About 40% of you replied that this would be as a senior scientist. Notably, while many had their first child as a student or postdoc, few early career scientists recommend it. Those who became parents as senior scientists are more happy about their timing. The general consensus is that at earlier career stages the main obstacles are low income, reduced flexibility in career path, and general instability, while at later career stages people are more loaded with various responsibilities and health issues become more relevant.

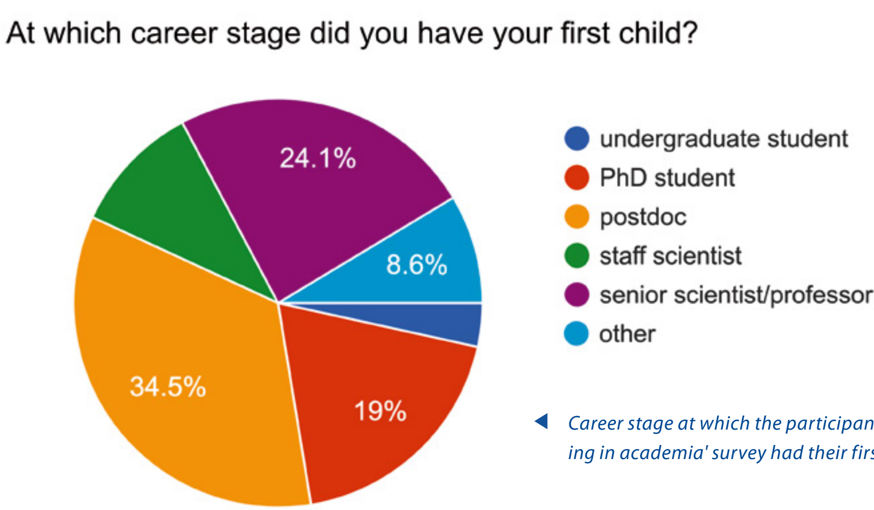
The common sentiment is expressed by one respondent: "There is never the best time. Go for it when it feels right and do not wait for the perfect / impactless moment, because it might not arrive."

Parenting in the LVK has its own caveats. Close collaboration between different parts of the world is a norm for us, with telecons at every time of the day (and night). This is challenging for many parents. One respondent writes: "I was no longer able to commit to working very long hours as I could before becoming a parent. This meant that I, for example, missed a lot of telecons and increasingly felt that I was no longer very much 'in the loop', so to speak." However, many also note that people in the collaboration are particularly positive and accommodating towards parents. While the LVK collaboration cannot do too much to support parents, a couple of things came up in the responses. First, a more consistent support at LVK meetings would be very welcome. This could be recommendations for daycare, organized child care at the meeting or financial support towards child care or travel. Secondly, the LVK stands in a unique position, with the potential to impact policy making in local universities or governments. Having a wide-spread network of working groups, a centralized effort from the LVK could have an impact on parent support in various forms.

Ultimately, children are a transformative experience. No one can fully prepare for that and predict the possible impact on their life and career. But we as a community can recognize and support the difficult work-life balance that parents have to navigate. It might be as simple as not setting telecon times at the typical "pickup from daycare" time, or avoiding passing judgment on a person's potential performance based on their having kids.

As Steven Penn wrote: "A good start is just awareness about people's parenting status and a welcoming attitude that one can be both a good parent and a good scientist."

You can find a more detailed overview of the survey results on the dcc: G2400187.



Career stage at which the participants of our 'parenting in academia' survey had their first child.

Building a gravitational-wave detector on the Moon

Joris van Heijningen

is an assistant professor at VU University Amsterdam and Nikhef. He works on cryogenic inertial sensors, mode match sensing and vibration isolation. Outside work, he sings and plays saxophone in jazz, rock 'n' roll and carnival bands.

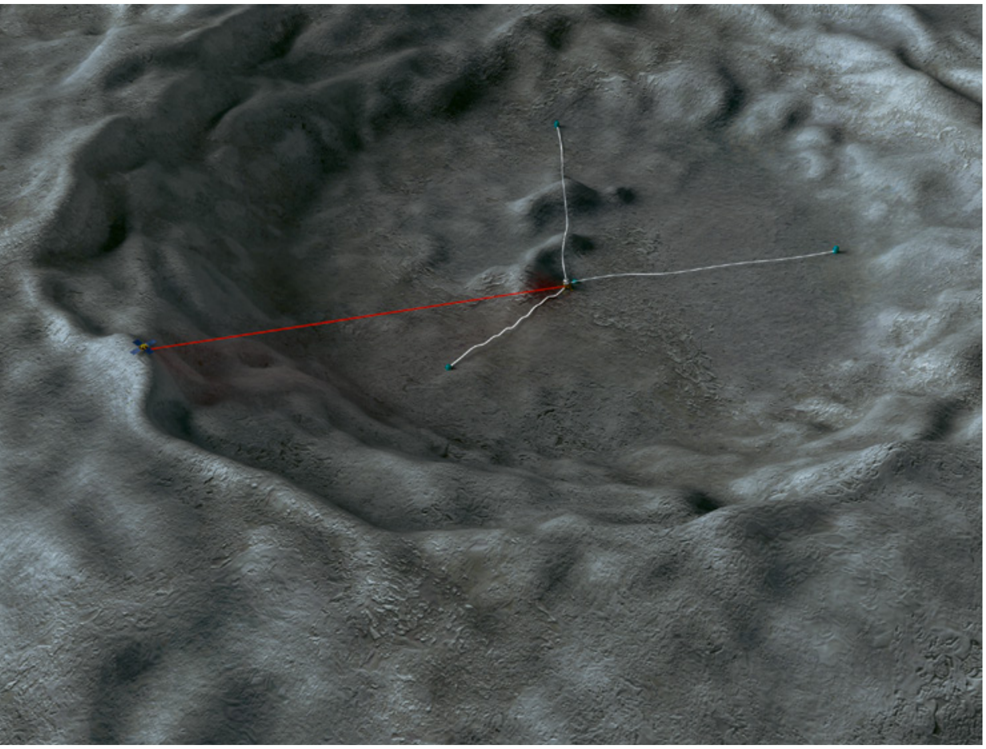


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Figure 1: *Mission sketch of LGWA. In a crater on the South pole of the Moon, an array of 4 seismic stations – each containing two inertial sensors – is deployed. The stations are connected to a central station, which receives power from a microwave beam. That beam is generated by a small station on the rim of the crater which draws power from a solar panel array. This is one of the powering options under investigation.*

Humanity is going back to the Moon! NASA's Artemis, ISRO's Chandrayaan and more planned missions; there is renewed interest to launch robotic and crewed missions to our nearest celestial body. Setting up a base as a stepping stone to Mars, lunar mining of Helium-3 and the rare Earth metals are just a few reasons to do so. Of course, you can also do science on the Moon and what better science than the gravitational-wave (GW) kind?

Joe Weber (with his associates) had originally intended to turn the Moon into a bar detector by having the Apollo 17 crew deploy their gravimeter [1] in 1972. Unfortunately, his experiment had a technical failure and was rendered useless for its intended goal.

Now that we are in the fourth observation run for the first GW observatories, the future landscape of detectors takes shape. The time seems ripe for the deployment of a successful lunar GW detector. The Lunar Gravitational-wave Antenna (LGWA) [2] concept goes beyond Weber's plans as it aims for a broadband sensitivity. LGWA will deploy femtometer-class inertial sensors, and the GW signal is recorded in the differential between the lunar surface motion and the motion of the proof mass, which is suspended from a frame inside the inertial sensor. The frame is rigidly attached to the lunar surface, which follows the Moon's elastic response to a passing GW. Precisely this elastic response gives a differential motion between proof mass and the frame attached to the lunar surface, and results in a GW signal. To distinguish between local phenomena like meteor strikes – even as tiny as milligram ones – and our beloved GW signal, several of these inertial sensors are required.

Sufficient sensitivity in the decihertz range can only be obtained by lowering the thermal noise in the inertial mass suspension. Besides using high quality materials and a low-frequency suspension, a cold place must be found. The temperature on the Moon varies wildly because of the lack of atmosphere, but craters on the lunar south pole provide permanently shadowed natural cryostats with steady temperatures below 40 K. Additionally, this lack of atmosphere, tectonic plates or oceans makes the lunar seismic environment an excellent spot for low-background precision measurement. Figure 1 shows an artist impression of the LGWA array deployed in the shadowy crater.

The Laser Interferometer Space Antenna (LISA) and the terrestrial Einstein Telescope (ET) and Cosmic Explorer (CE) carve out deep sensitivity curves as shown in figure 2. LGWA aims to bridge the gap between LISA and ET in the decihertz regime (0.1 – 1 Hz). The LGWA curve constitutes of the thermal noise divided by the Moon's resonant behavior below 0.3 Hz. Beyond that, the readout noise – either interferometric or superconducting [3] – adjusted for the Moon's reduced response at high frequency. It is impossible to detect GWs on Earth below a few Hz due to the microseismic peak (impact of ocean waves) and challenging to have decent sensitivity above a few 100 mHz using satellites as it requires optical cavities between satellites. There are also lunar interferometric concepts, but they seem technologically far away. LGWA may be the fastest way to decihertz detections.

What science can we do with LGWA? We will see heavier binary black hole inspirals than terrestrial detectors and predict the ones that will show up in Earth's detectors as can be seen in figure 2. LGWA has its largest detection horizon for 1000 solar-mass binary black holes, which would allow us to probe their population in the early Universe. Apart from black holes, double white dwarf systems can be detected well beyond our galaxy, which could finally prove them to be progenitors to type Ia supernovae [4]. Detection of binary neutron star systems like GW170817 with LGWA will lead to early warning, some years in advance, which enables studying kilonovas from their onset. Then, regarding tests of fundamental physics, such as General Relativity, probes of dark matter and of dark energy models, observations by LGWA will be independent and complementary to those obtained by other detectors. This may lead to possible hints of new physics in a different class of sources.

It would be fantastic if all detectors shown in figure 2 will be observing simultaneously. For LGWA to operate alongside LISA, an aggressive timeline should be adopted. However, things can go fast in space. The technology for the inertial sensors, deployment, powering, data uplink is all under development. Uncertainties in the seismic background and geology of the lunar craters will partially be resolved by a pathfinder mission coined Soundcheck. This mission will constitute of a single inertial sensor on a lander in a permanently shadowed crater. It will detect or put more stringent limits on the lunar seismic background as well as test various technologies needed for the full LGWA mission.

One could think of our ability to hear the full GW spectrum as a symphony orchestra under construction. We can listen to the terrestrial piccolo flutes, the space-borne cellos, the pulsar timing array of basses and the inflationary contrabass tubas. Some instruments are still missing, such as the lunar violins.

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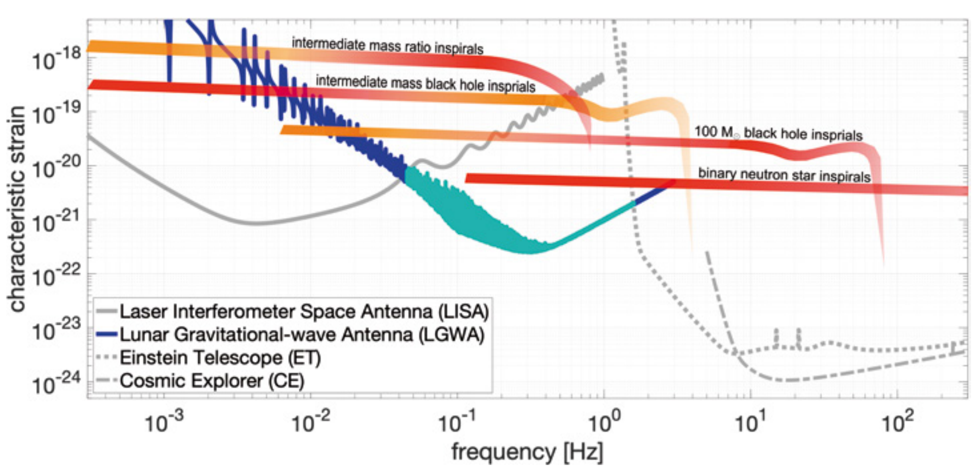


__Figure 2:__ Modelled LGWA sensitivity compared to LISA, ET and CE with a cyan highlight of where LGWA would bridge the decihertz band. The notch peak structures in the LGWA curve are the inverse response of the Moon to passing GWs. Several traces of expected sources are shown that represent up to 5 years of frequency evolution.

Graeme Eddolls

completed his PhD at the University of Glasgow in 2022, focussing on cryogenic silicon suspensions. He briefly left the LIGO-Virgo-KAGRA (LVK) to pursue his private pilot's license in Canada, before returning to work at Glasgow on LISA. Graeme is now back in the LVK as a postdoc at Syracuse University.

Leon Trimble

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

Making a Splash with Gravitational Waves

▲ *Participants in the pool enjoying the above-water and underwater cosmic sounds produced by Leon Trimble and Joel Cahen at Arlington Baths.*

Have you ever wanted to dance to the sounds produced by gravitational waves? How about swim amongst them? That's exactly what Swimming with Gravitational Waves, hosted by the Institute for Gravitational Research (IGR), University of Glasgow, recently achieved in a unique and immersive outreach experience, supported by the Institute of Physics (IOP) Scotland.

This new event was held at Arlington Baths, a Victorian baths in Glasgow in November 2023, after a successful first appearance at Moseley Road Baths, a community-restored Victorian baths in Birmingham in July 2023. These two events were a sell-out success with many people from the local communities taking part in the unique event that is quite different from most engagement activities.

Before donning their swimsuits and hopping into the pool, attendees were treated to a short introductory overview of gravitational waves and their ongoing detection by the LIGO-Virgo-KAGRA (LVK) collaboration by one of the organisers, Andrew Spencer, a lecturer at the University of Glasgow.

But this wasn't just for a casual paddle or energetic workout. Waiting for them by the pool were modular synthesist and visual artist, Leon Trimble, and underwater sound specialist and experiential artist, Joel Cahen. Leon has previously worked with some of our LVK colleagues at the University of Birmingham (LIGO Magazine issue 18 3/2021, p. 15), and with me using his laser interferometer-fed modular synthesiser, the Gravity Synth. The Gravity Synth produces both audio and visual engagement themed around gravitational-wave detection, neatly linking the detection principles directly to the art and science experienced by the public. Leon, who devised and designed the Gravity Synth in collaboration with LVK members, has performed on the BBC World Service, Abbey Road Studios and at the KTH Royal Institute of Technology, sending cosmic sounds to be bounced off the moon! This same Gravity Synth was used here, except to improve the event even further, not only was the interferometer-synthesiser fed into above-water speakers around the pool, but also to a separate speaker system, with entirely different sounds, used underwater! Joel used his expertise to rig these special underwater speakers. The final 15 minutes of the hour-long session was reserved for Joel to really experiment and show off the full potential of his underwater sound system. People were encouraged to float, swim and dive their way through the sonic and tactile landscape of the pool to discover the eerie sounds produced by the modulated interferometer.

In my opinion, not only does this event provide real collaborative outreach between science and art, but it was also created with immersion, in all senses of the word, in mind, combining physical activity with accessible and alternative forms of outreach. Simultaneously enjoying both sound and water waves after a mini lecture about gravitational waves really helps the imagination square the triangle of these three modes of learning. Thankfully the organisers and volunteers were able to experience this for themselves in the final pool session. The benefits of this immersive experience were reflected in the feedback from attendees, who expressed great enthusiasm and support for future events like this throughout Scotland, the UK and the world. “[I specifically enjoyed] the combination of scientific theory and play - the underwater speakers were the highlight,” noted one attendee, while others appreciated how accessible, unique, and fun the event was.

Our thanks go to IOP Scotland and both the Arlington and Moseley Road Baths for smoothly running the events. We’d like to pay a particular tribute to the lifeguards for not only keeping everyone safe, but expertly keeping their cool as they watched numerous individuals floating face down in the pool with their head under the water listening to the underwater cosmic sounds!

Check out a short video of the event, produced by Daniel Williams, a postdoctoral researcher at the University of Glasgow at tinyurl.com/GravSwim.

“I came up with the idea of Swimming with Gravitational Waves when I was asked to do an artistic residency in N. Devon (that later fell through) and as it was a coastal gallery I started to think about gravitational waves in the context of water. The possibilities of playing the Gravity Synth concert in a tidal pool (I’m still working on that). I asked around my artist friends […] and a couple of people suggested other artists, like Kate Carr but also Wet Sounds (Joel Cahan) who specialises in underwater installations.

“The wonderful Victorian Moseley Road baths very near to my house (my grandfather worked there) was a good place to test this out as I had already held a very successful event there, The Drone Bath, in 2022. [...] The old public bath cubicles each had a modular musician in (including snooker legend Steve Davis!) contributing to a huge droning ambience, so I organised it there for a sell out underwater show in the still functioning Women's Pool with Dr. Spencer giving the intro. The baths are now closed and will be restored to their former glory over the space of 5-10 years."

Leon Trimble

Organisers and volunteers; (L-R back) Dr Daniel Williams, Naren Nagarajan, Jennifer Docherty, Phoebe Utting, Dr Graeme Eddolls, Dr Andrew Spencer. (L-R front) Leon Trimble, Joel Cahen.

From pulsars to speech enhancement

Gravitational Wave (GW) researchers describe GW astronomy as a way of "listening to the Universe" and we sometimes compare our observatories to sensitive microphones; after some processing, we can even hear the chirping from the signals generated by merging black holes. This close relationship between GW data and audio recently proved to be useful when I left academia and moved into industry.

In 2022, my family relocated to Cambridge, UK and, after 20 years in GW research, I was after a new job, hoping to find something in a science-based sector that would involve some aspect of research. During my search, I learned of a position as an Audio Algorithm Researcher at CEDAR Audio Ltd. CEDAR started as a spin-out from a group at Cambridge University working on audio restoration, and has since become a world-leader in dialogue noise suppression, extracting clean signals from a noisy time series. Does this sound familiar? Consequently, the digital signal processing and Bayesian inference skills I had gained from dealing with GW data proved to be a very good fit for my new role.

Matt Pitkin was formerly a Lecturer at Lancaster University and co-chair of the LSC continuous-waves working group, and now works as an Audio Algorithm Researcher for CEDAR Audio Ltd. He occasionally attempts to drum and kayak, but not at the same time.

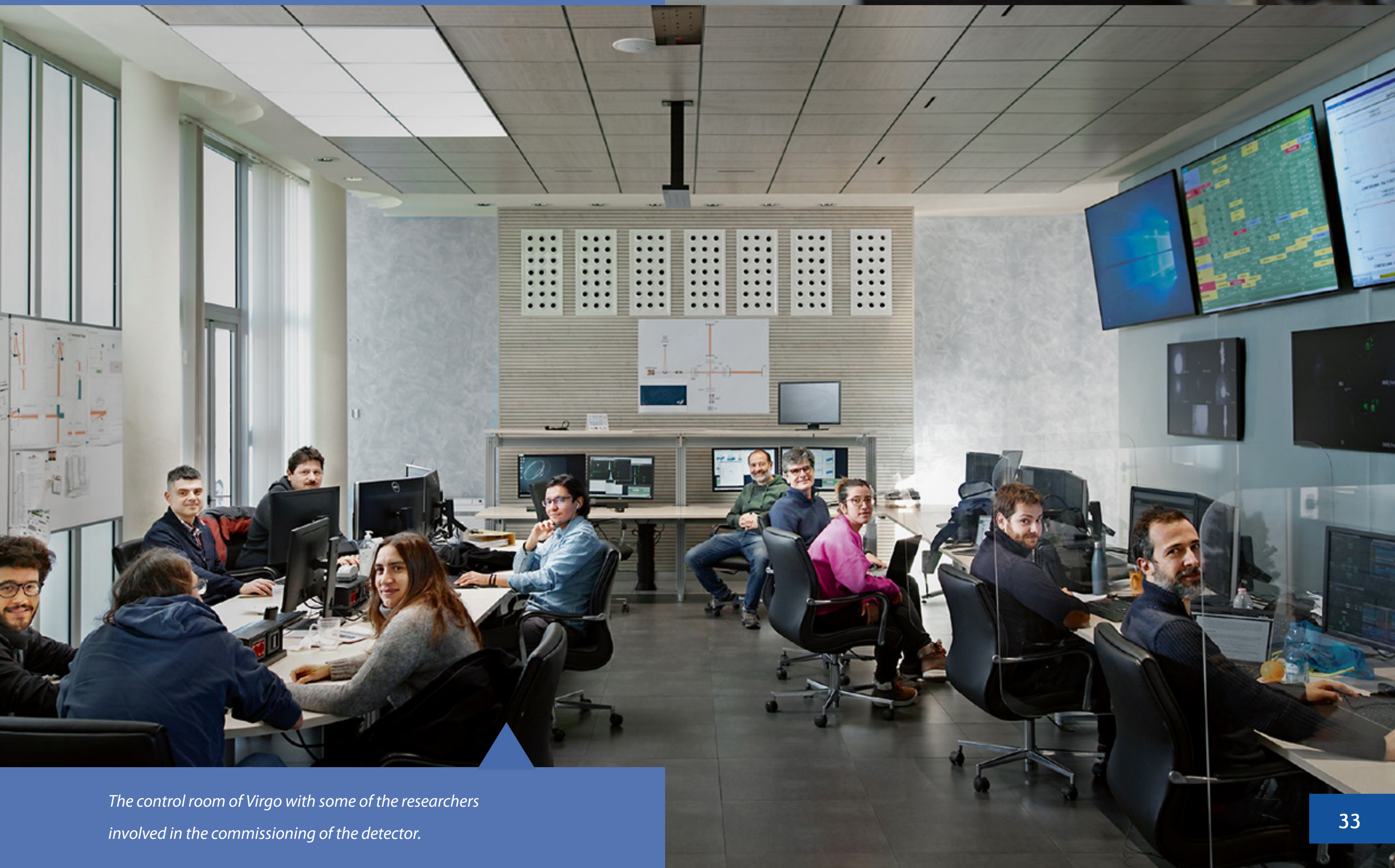
CEDAR is on a different scale to LIGO-Virgo-KAGRA or large tech firms located around Cambridge, and its small size means there is a very close link between research and product development. So far, I have been involved in the development of two new processes; one using traditional digital signal processing while the other utilises deep neural networks. Both have required extensive listening tests to ensure optimum listenability or improved intelligibility, which are quite different requirements. The results of these tests can be quite subtle, and my untrained ears can sometimes struggle to identify the artefacts that the more experienced members of staff can hear.

The company manufactures software and hardware, so it's necessary to think in advance about how a process might work when implemented within a software suite or when embedded in a device. This means that I have to think about practicalities such as algorithm latencies and hardware constraints. Furthermore, processes can have multiple applications ranging from live broadcast to forensic audio investigation, so the workflows of each type of customer must be considered. For example, minimal latency and undistorted speech are the primary criteria in live broadcast whereas, in a forensic application, intelligibility would be prioritised over both latency and changes to the voice.

An appealing feature of my job title is that it contains the word "Researcher". I've had to use my skills to delve into the literature to discover the state-of-the-art before developing and testing new ideas. While the aim is to create something that can be turned into a product, I still have the freedom to explore different ideas. Happily, CEDAR retains strong links with the university sector, and in particular with groups at Cambridge and Imperial College, so I have been able to engage with these.

I have not completely left GWs behind. Having spent so many years looking for GWs from pulsars, I couldn't leave before we had seen our first continuous-wave signal. I've been able to stay in LIGO-Virgo-KAGRA at a low level, being affiliated through the group in Cambridge.

At work on one of the optical benches of the Virgo detector.



The control room of Virgo with some of the researchers involved in the commissioning of the detector.

Career Updates

David Keitel has become a permanent professor at the University of the Balearic Islands since December of 2023.

Eleonora Polini completed her Ph.D. in France at the Université Savoie Mont Blanc and the Laboratoire d'Annecy de Physique des Particules, under the supervision of Edwige Tournefier.

Luis Diego Bonavena ("Diego") has joined the University of Florida group. Diego got his PhD at the University of Padova and is working on instrument science for LIGO and the optical design of Cosmic Explorer.

Michmiura Yuta, Research Scientist at Cal-tech, will be starting as an Associate Professor at RESCEU, University of Tokyo from April 1st, 2024. The group will focus on the commissioning and upgrades of KAGRA, and R&D for Voyager and other future detectors. Research plans also include developing tabletop experiments to search for dark matter, signatures of quantum gravity, Lorentz violation, and any fun physics.

Seth Linker, a researcher at California State University Los Angeles and part of the Optics Working Group, completed and was awarded his PhD from the University of Sannio, Benevento Italy for his thesis: 'Limiting Crystallite Size in Dielectric Optical Coatings for Interferometric Gravitational Wave Detection'. A portion of the observations and conclusions from the work of that thesis has also just been published in the journal Classical and Quantum Gravity, issue: "Focus on the development of low-noise thin film coatings for future gravitational-wave interferometer mirrors".

Sumeet Kulkarni graduated in January 2024 with his Ph.D. from the University of Mississippi. He is going to join Nature as a spring science writing intern.

Yanyan Zheng earned her PhD from Missouri University of Science and Technology in November 2023, with a thesis on "The Science of Gravitational-Wave Sources and Beyond Compact Binary Coalescences." She is now a temporary research scientist at Missouri S&T, continuing her work on LVK data analysis and detector characterization for the Missouri LIGO group.

Awards

Alessandra Buonanno has been awarded the 2023 Oskar Klein Medal by the Stockholm University and the Nobel Committee of the Royal Swedish Academy of Sciences. (https://www.aei.mpg.de/1092354/alessandra-buonanno-awarded-oskar-klein-medal?c=26160)

Cailin Plunkett was awarded the APS' LeRoy Apker Award for her undergraduate work (https://www.aps.org/programs/honors/prizes/prizerecipient.cfm?last_nm=Plunkett&first_nm=Cailin&year=2023)

Eleonora Polini was honored with the GWIC-Braccini Prize for the best doctoral thesis defended in 2022 in the field of gravitational waves last summer. She also received an award from the Accademia Nazionale dei Lincei in Italy for her master's thesis work on the NAOJ experiment on frequency-dependent squeezing, whose ceremony took place in November 2023 (https://www.lincei.it/it/news/assegnati-i-premi-dellaccademia-dei-lincei-2023). Eleonora was also awarded the Virgo award "for sustained contributions to optical benches and squeezing activities". She was involved in many of the optical installation, mitigation of scattered light and commissioning activities related to the suspended benches of Virgo (mainly of the detection and squeezing systems). She spent one year (10 months) on the EGO-Virgo site to fully devote her time to the commissioning of the frequency-dependent squeezing (FDS) system.

Henning Vahlbruch, Benno Willke, and **Hartmut Grote** have been awarded first prize in the Berthold Leibinger Innovationspreis 2023 for "ultra-high precision beam sources not only for basic research". (https://www.aei.mpg.de/1073199/berthold-leibinger-stiftung-zeichnet-laser-forscher-aus-hannover-und-cardiff-aus?c=26160)

Juan Calderón Bustillo (University of Santiago de Compostela) and Nicolás Sanchis-Gual (University of Valencia) have been awarded the prestigious "Ramón y Cajal" Fellowship by the Spanish Ministry of Science. This Fellowship grants a tenure-track position in any Spanish University that the recipient chooses.

Liu Tao from the University of Florida has won the Tom Scott Memorial Award. This award is made annually to a senior graduate student in experimental physics at the University of Florida who has shown distinction in research.

Neil Lu, Susan Scott, and **Karl Wette** (Centre for Gravitational Astrophysics, ANU) received the 5th Award in the Gravity Research Foundation 2023 Awards for Essays on Gravitation for their essay "What are neutron stars made of? Gravitational waves may reveal the answer" (https://www.gravityresearchfoundation.org/s/2023-GRF-Awards.pdf). The essay was published in a special issue of International Journal of Modern Physics D in October 2023 (https://arxiv.org/abs/2305.06606).

Sumeet Kulkarni was awarded the 2023 Eric & Wendy Schmidt Award for Excellence in Science Communications by the National Academies of Sciences, Engineering, and Medicine

Susan Scott (Distinguished Professor at the Centre for Gravitational Astrophysics, ANU) has received the 2023 Peter Baume Award by the Australian National University. This is the ANU's most prestigious award and recognises eminent achievement and merit of the highest order.

New LSC positions

The LAAC (LSC Academic Advisory Committee) election results are **Sarah Caudill** as co-chair, **Sama Al-Shammari** as graduate representative, **Aditya Vijaykumar** as

New LSC positions cntd.

postdoc representative, and **Ofek Birnholtz** as senior member co-chair.

Andri Gretarsson has been elected as Optics working group co-chair.

Daniel Brown has been elected as Advanced Interferometer Configurations chair.

Jenne Driggers is the now LSC Operations Division chair.

Mikhail Korobko has been elected as Quantum Noise working group chair.

Stefan Balmer has been elected as Technical Advisor to the Oversight Committee.

Volker Quetschke has been re-elected as Lasers Auxilliary Optics working group chair.

Other News

LIGO members **Debatri Chattopadhyay** and **Isobel Romero-Shaw** undertook a three-week voyage to Antarctica in November 2023 as part of Homeward Bound, a global leadership initiative for women and non-binary people in Science, Technology, Engineering, Maths and Medicine (STEMM), which aims to facilitate radical changes in leadership for a sustainable and equitable future. Despite unforeseen challenges, the expedition of over 100 participants was successful, and involved networking, strategising and brainstorming with a backdrop of vast, uninhabited wilderness.

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A dusting of snow at the LIGO Hanford Observatory during Observing Run 4. See also the cover page image caption on page 2.

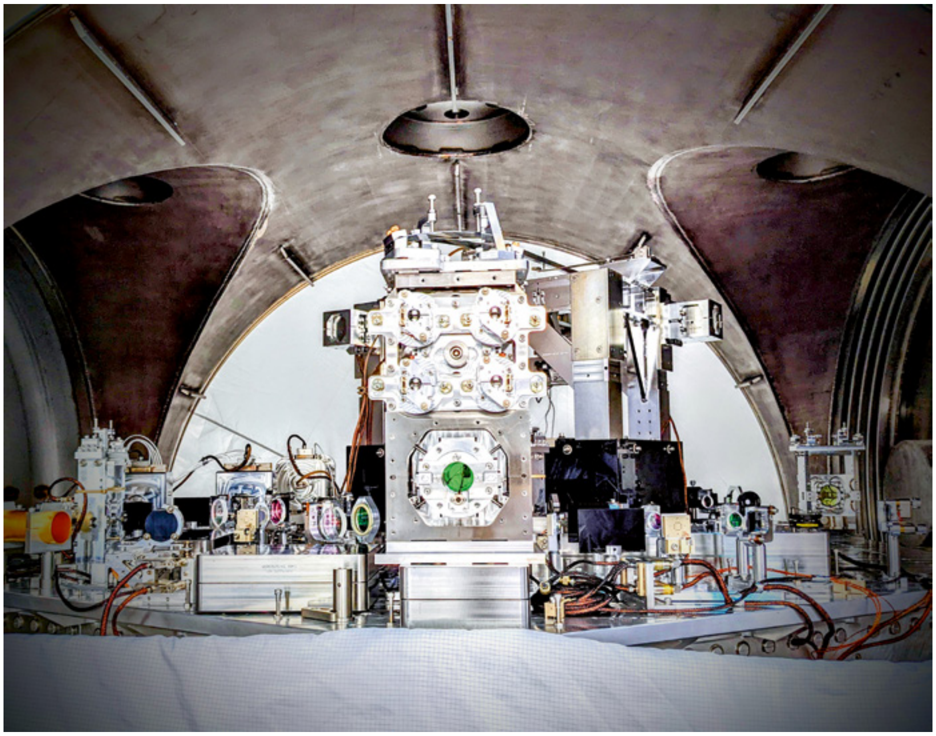
To observe the mergers of black holes and neutron stars in distant galaxies, hundreds of millions of lightyears away, the LIGO detectors require extremely high laser powers. As the laser beam bounces around the detector, a fraction of it is absorbed into the glass optics, unfortunately causing them to heat up and expand ever so slightly. This in turn changes the shape of the laser beam passing through them, preventing the laser power from being efficiently transferred between parts of the detector and limiting the overall sensitivity of the observatory.

To help alleviate these thermal deformations, and allow LIGO to operate with greater laser power and observe further into the universe, a variety of compensation systems are placed throughout the detector. One of these is the suspended active matching stage, or SAMS, actuators. SAMS dynamically adjust the shape of the injected laser beam by deliberately changing the shape of a mirror. This adjustment compensates for the unwanted effects of heating inside the detector.

Two variants of the SAMS are in operation. The Thermal-SAMS (TSAMS) features a mirror that is shrunk-fit inside an aluminum disk. By heating the disk it expands, reducing the force on the mirror, along with its curvature. Therefore, by heating and cooling the disk, the curvature of the mirror and reflected beam can be controlled. Operating on a similar principle, the Peizo-SAMS (PSAMS) features a mirror held rigidly in an aluminum disk, with a set of Piezoelectric actuators used to press on the rear of the mirror. Piezoelectric crystals expand as an electrical voltage is applied to them, giving control over the force on the back of the mirror, and hence its curvature.

Together, the SAMS mirrors help ensure that as much laser power as possible is passing through the detector, allowing us to observe far into the universe.

T-SAMS installed in HAM-7 at LIGO Hanford.



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