LIGO Scientific Collaboration

Gravitational Wave Astronomy

LIGO MAGAZINE

#29
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A+ Bigger beamsplitters

A major upgrade for LIGO's A+ phase

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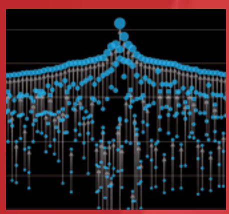
GWTC-5.0 – the catalogue continues: 161 events added to the collection

The total is now a whopping 390 signals! p.6



LIGO–Virgo–KAGRA teamwork: Gravitational-wave autotune

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Plus A decade on... LISA Pathfinder persists in discovery p.28

Front cover

A major upgrade was recently completed at LIGO: the installation of a brand-new bigger beamsplitter optic. At 45cm in diameter, this new beamsplitter is 22% bigger than the original optic, and aims to increase the efficacy of quantum squeezing. This is one of the major upgrades planned for the A+ phase of LIGO. Find out more on pp. 19-21.

Top inset: GWTC-5.0 is the fifth gravitational-wave transient catalogue, adding 161 events to the collection. The image represents all the binary mergers observed so far. Article on pp. 6-7.
Bottom inset: What do you do when a chirp is out of tune? Find out how astrophysical calibration has been used to analyse two recent gravitational-wave signals on pp. 8-10.
Bottom-left (diagonal) inset: A mural of the Inter-University Centre for Astronomy and Astrophysics (IUCAA) logo at Pune.
Article on pp. 6-7.

Image credits

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Cover: Main image: Beamsplitter installation photo by Tom Roocke / Madison Simmonds. Top inset: Masses in the stellar graveyard image by LIGO-Virgo-KAGRA / Aaron Geller / Northwestern. Bottom inset: Astro-calibration image by Carl Knox, OzGrav/Swinburne. Bottom-left (diagonal): Image courtesy of IUCAA.

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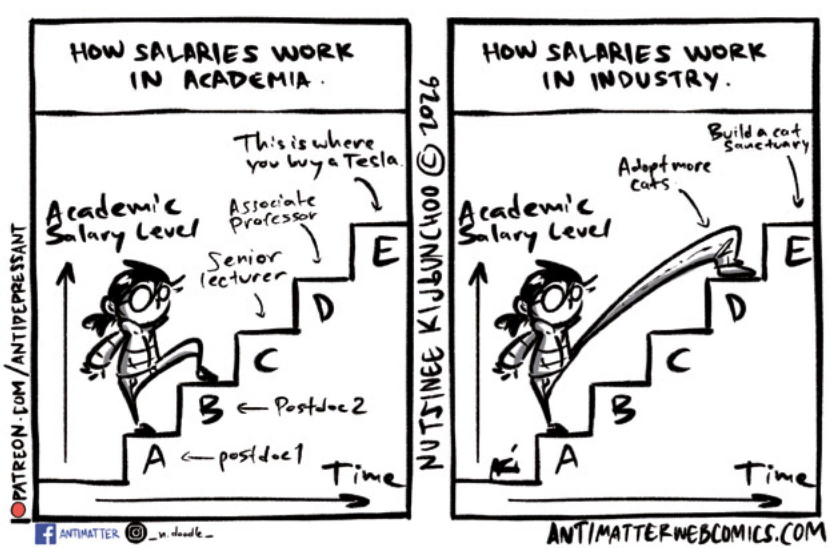


Welcome to the 29th issue of the LIGO Magazine!

Hannah Middleton
Editor-in-Chief

Anna Green
Deputy Editor-in-Chief

Welcome to the twenty-ninth edition of the LIGO Magazine.

In this edition, we take a look at the latest iteration of the gravitational-wave transient catalogue with Sanika Khadkikar, Storm Colloms and Alex Papadoupoulos as our guides to what's new in GWTC-5.0. Observing gravitational-wave signals requires accurate detector calibration, whilst miscalibration can lead to incorrect results. What do you do if a gravitational-wave chirp is out of tune due to miscalibration? Ling Sun and Christopher Berry explain calibration on the back cover, and share how astrophysical calibration is now aiding our detections in "Chirps out of tune".

Did you know LIGO recently installed new beamsplitters? Check out some wonderful photos of the installation from Tom Roocke in "Installing LIGO's bigger beamsplitter". We also hear from Alicia Calafat and Joan-René Mérou on their journey from Mallorca to Hanford as LIGO Fellows. The search for long-lasting (or continuous) gravitational-wave signals faces the challenge of noise imposters, but Christine Lee & Evan Goetz are combating them with all-important detector characterisation in "Narrowband Noise Impostors in LIGO Detectors".

This September, the community is gathering in beautiful Pune, India for the LIGO-Virgo-KAGRA (LVK) Meeting: Sayantani Datta and Shubhagata Bhaumik share all you need to know about our LIGO-India hosts. Over in LAAC Corner, the focus is on thesis writing – how long does it take, when should you start, and how much work is it? And our latest in the Climate Change Conversations series focuses on the use of AI in our work and its impact on the environment.

This issue, we remember the lives of several members of our gravitational-wave community who have recently passed away in "Remembering...", they will be sadly missed.

We also hear from Diana Haikal on "Inspiring the next generation by creating opportunities" and Ana Schurmann describes how gravitational waves can be used to make music in the "Gravitational Wave Symphony", catch up with Rory Smith on his work on generative instrumentation at Liquid Instruments in Work after LIGO, and find out about new results with LISA Pathfinder data 10 years on in Meanwhile in Space.

Finally, on a personal note, Hannah will soon be heading off on maternity leave! But LIGO Magazine will be safe in the capable hands of Anna and the whole editorial team while she is away.

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

The past few months have been an exciting and productive period for the LIGO Scientific Collaboration and the wider gravitational-wave community. The "astro calibration" analysis described in this issue highlights the interplay between instrument science, data analysis, and our understanding of relativistic astrophysics. The release of GWTC-5, adding more than one hundred confidently detected binary merger events to our catalogue, has provided a wealth of new information for studies of compact binary populations, cosmology, tests of general relativity, and other areas of gravitational-wave science. At the same time, additional results continue to emerge from the full Observing Run 4 dataset, including searches for stochastic backgrounds, continuous-wave signals, and gravitational-wave transients. It is remarkable to see the pace at which the collaboration continues to analyse data and translate observations into high-impact scientific discoveries.

We are approaching an important milestone with the start of the IR1 run, and preparations across the detector network have progressed well. At the LIGO observatories, significant upgrades include larger beam splitters at both sites and a jitter attenuation cavity at LIGO-Hanford. These developments are expected to enhance operational stability during IR1 and also move us further along the path toward the A+ detector era, enabling future observing campaigns with even better sensitivity. On behalf of the collaboration, we would like to congratulate and thank the instrument science teams and observatory staff whose dedication, expertise, and hard work continue to make these advances possible.

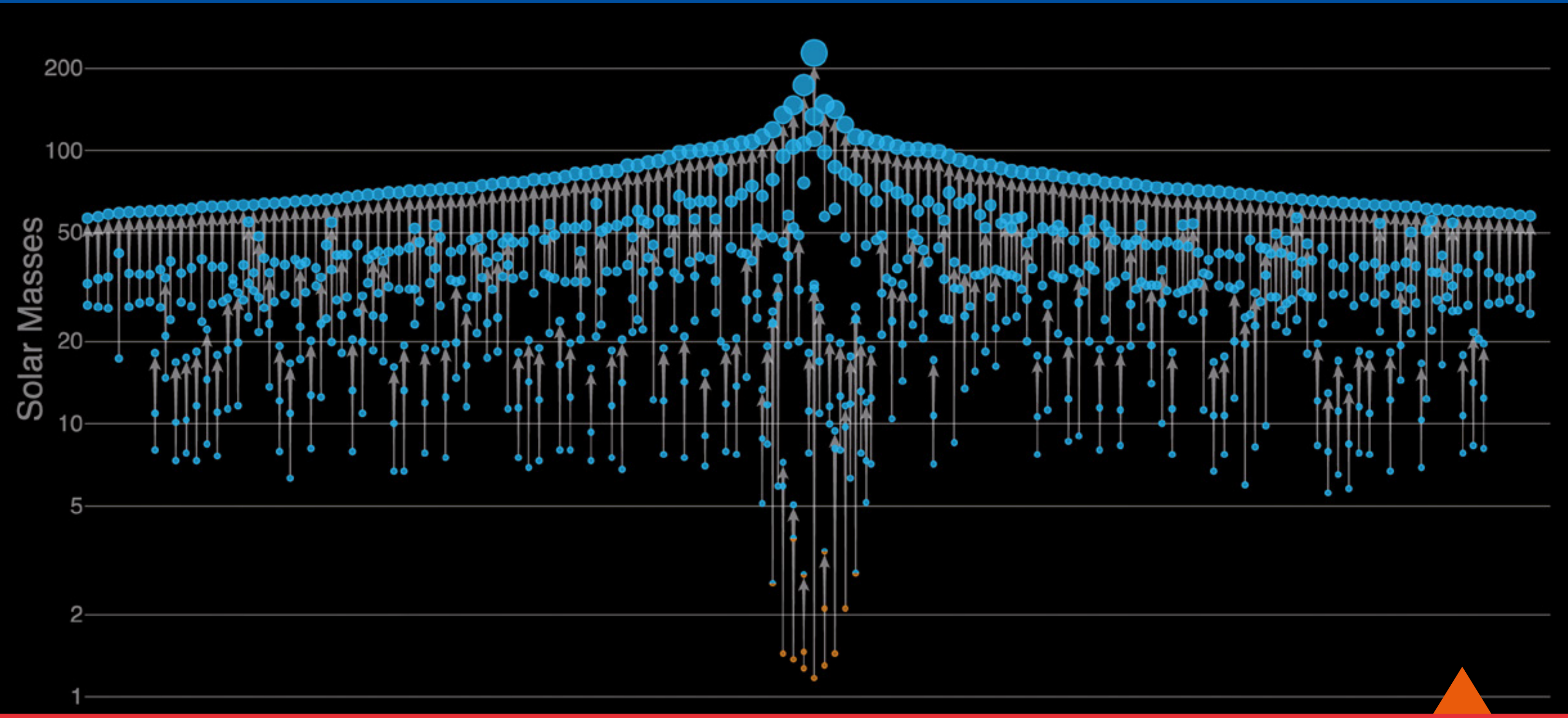
Beyond the detectors themselves, we are moving steadily toward a truly global gravitational-wave observatory network. The increasing level of international cooperation among detector facilities and scientific collaborations promises to expand both our scientific reach and our ability to respond rapidly to new discoveries. Every improvement to the network increases our ability to detect, characterize, and localize gravitational-wave sources, opening new opportunities for multi-messenger astronomy and for understanding the most extreme phenomena in the Universe.

It is particularly fitting to reflect on this global future as we gather for a LIGO-Virgo-KAGRA collaboration meeting in India. India has long been home to a vibrant and influential gravitational-wave community, whose members have contributed across the full breadth of gravitational-wave physics, instrumentation, data analysis, and astrophysics. In recent years that community has grown substantially in preparation for the construction of LIGO-India, and it is inspiring to see the project moving from planning into reality. Construction activities are well underway, and we look forward to following the progress toward the completion of the facility and the eventual installation and commissioning of the detector. The addition of LIGO-India will greatly enhance the detection and localization capabilities of the global network for our continued exploration of gravitational-wave astronomy.

Stephen Fairhurst
LSC Spokesperson

Peter Shawhan
LSC Deputy Spokesperson

161 additional events have been added



Masses of black holes (blue) and neutron stars (orange) detected by LIGO-Virgo-KAGRA up to GWTC-5.0.

GWTC-5.0: The catalogue continues

The LIGO-Virgo-KAGRA (LVK) Collaboration recently released the latest edition of the Gravitational Wave Transient Catalogue (GWTC-5.0). Continuing to build on previous catalogues, a total of 161 events detected between April 2024 and January 2025 have been added to the collection. The total is now a whopping 390 signals!

Catalogues represent the work of a huge number of people – a real LVK team effort spanning many timezones with activities ranging from work on the detectors themselves to the analysis pipelines and the paper writing and data releases. Here we catch up with just a few LVK members who were part of different teams working on the new observations to ask about their GWTC-5.0 highlights, plus their favourite new gravitational-wave observations!

Sanika Khadkikar

is a fourth-year graduate student at Pennsylvania State University, where her research uses neutron stars as astrophysical laboratories to study fundamental physics through gravitational waves, electromagnetic astronomy, nuclear physics, and quantum chromodynamics. Beyond research, she has a deep passion for theatre arts and cinematography, which she enjoys exploring in her spare time.

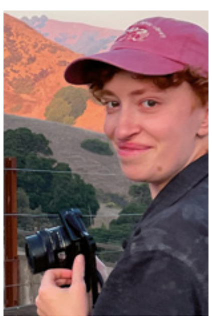
Has anything changed in the work of GWTC-5.0 compared with how things were done with GWTC-4.0?

Sanika: As a collaboration, we strive to maintain a consistent process across GWTC releases so that the catalogues remain uniform and easy to use. One notable change in GWTC-5.0 was the inclusion of an additional parameter-estimation pipeline, RIFT (Rapid Iterative FiTting). Having multiple independent pipelines helps increase confidence in our results by allowing them to be reproduced using different analysis methods. Integrating RIFT into the existing framework required significant coordination across the GWTC-5.0 analysis team, but it was rewarding to see it successfully become part of the catalogue release process!

What is your favourite new GWTC-5.0 event and why?
Sanika: My favourite GWTC-5.0 event is GW250114 because it highlights just how far gravitational-wave astronomy has come since the very first detection, GW150914. The two signals are like cousins, with remarkably similar source properties. Yet the quality of the GW250114 signal reflects nearly a decade of progress in detector sensitivity and data analysis techniques.

One of the things that struck me most was how clearly we could observe the waveform. Comparing GW250114 to GW150914 feels a bit like comparing a high-definition image to an old pixelated photograph. It's a powerful reminder of how much can be achieved through years of technological development and collaboration. Seeing that progress reflected so directly in the data is both exciting and inspiring!

Storm Colloms



has just finished their PhD at the University of Glasgow, working on understanding the astrophysics of binary black holes from the observed population, including as part of the GWTC-5.0 astrodistributions paper writing team. They also enjoy making pottery and spending time with their cat Pico.

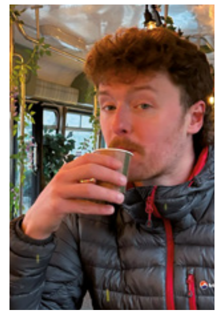
What astrophysics can we do with a catalogue of almost 400 events?
Storm: With GWTC-5.0, we can measure the masses, spins and distances of binary black holes, and probe the correlations between these properties with more precision than ever before. In particular, we find that black holes with different mass ranges have different spins, indicating that there are distinct formation pathways to create unique groups of systems. Now, we have growing evidence that there are ways that merging black holes are created in addition to their direct formation from massive binary stars.

What is your favourite new GWTC-5.0 event and why?
Storm: My favourite events are GW241011 and GW241110, pairs of black holes with clearly measured high spins

GW241011 and GW241110 are pairs of black holes with clearly measured high spins and unequal masses. These two observations showed characteristic signs that the larger black hole in each pair was formed not directly from a massive star, but from a previous merger of two black holes.

and unequal masses, hinting at these unique formation pathways. These two observations showed characteristic signs that the larger black hole in each pair was formed not directly from a massive star, but from a previous merger of two black holes. Signatures of these hierarchically formed black holes persist in the population as a whole, indicating that GW241011 and GW241110 are not one-of-a-kind, but trace an underlying trend. Non-scientifically, their names are very satisfying to me, I like to think of them as 'twin' observations.

Alex Papadopoulos



is a PhD student at the University of Glasgow, who works on gravitational wave cosmology with standard sirens. Outwith gravitational waves he enjoys fencing, hiking and watching Scotland lose football matches.

Can almost 400 events also tell us about cosmology?
Alex: The growing catalogue of gravitational wave events means we can produce the best constraint on the Hubble constant to date, using gravitational waves as an independent probe. Having a greater number of events, and in particular those with better sky localisations – thanks to the return of Virgo for Observing Run 4b – helps to narrow our errors by almost 25% over GWTC-4.0. These smaller sky localisations are helpful as they allow us to narrow down the number of potential hosts for the merger, and thereby improve our estimate of its redshift.

What is your favourite new GWTC-5.0 event and why?
Alex: My favourite new GWTC-5.0 event is GW240615, which holds the record for the smallest sky localisation area. Despite being over 1 Gigaparsec away, the signal was pin-pointed to 6 square degrees in the sky. Events such as this have the potential to be very cosmologically informative when used as standard sirens.

Chirps out of tune — these data are miscalibrated!

Calibrating a detector with a binary coalescence signal: An artist's impression of astrophysical calibration.

GW240925 arrived at a mischievous time. For a two-hour stretch, and only that two-hour stretch, LIGO-Hanford had been incorrectly calibrated. Accurate calibration of the detectors is important for analyzing any signals. Miscalibration can lead to incorrect conclusions about the signal or its origins. Therefore, you really do not want a signal to arrive when there is a calibration issue. Yet this was when GW240925 was discovered.

The event itself was a beautiful binary black hole chirp. One of the loudest ever detected! It was a signal people were excited to analyse. However, the calibration team quickly warned the parameter-estimation* team: "Wait a second — these data are miscalibrated!" A plan was promptly put together to analyse the signal assuming large calibration uncertainties.

"Look at these results," one of the key parameter-estimation analysts got excited and shared a plot, "the posteriors seem informative!" In other words, the data seem to be telling us something about how Hanford was miscalibrated at the time when the signal arrived. This was a neat result — using the signal to check the detector's calibration — but there was still one more surprise. When we compared the results calculated using the signal with the calibration team's careful measurements, the two seemed to point in opposite directions. "That cannot be right…"

Ling Sun

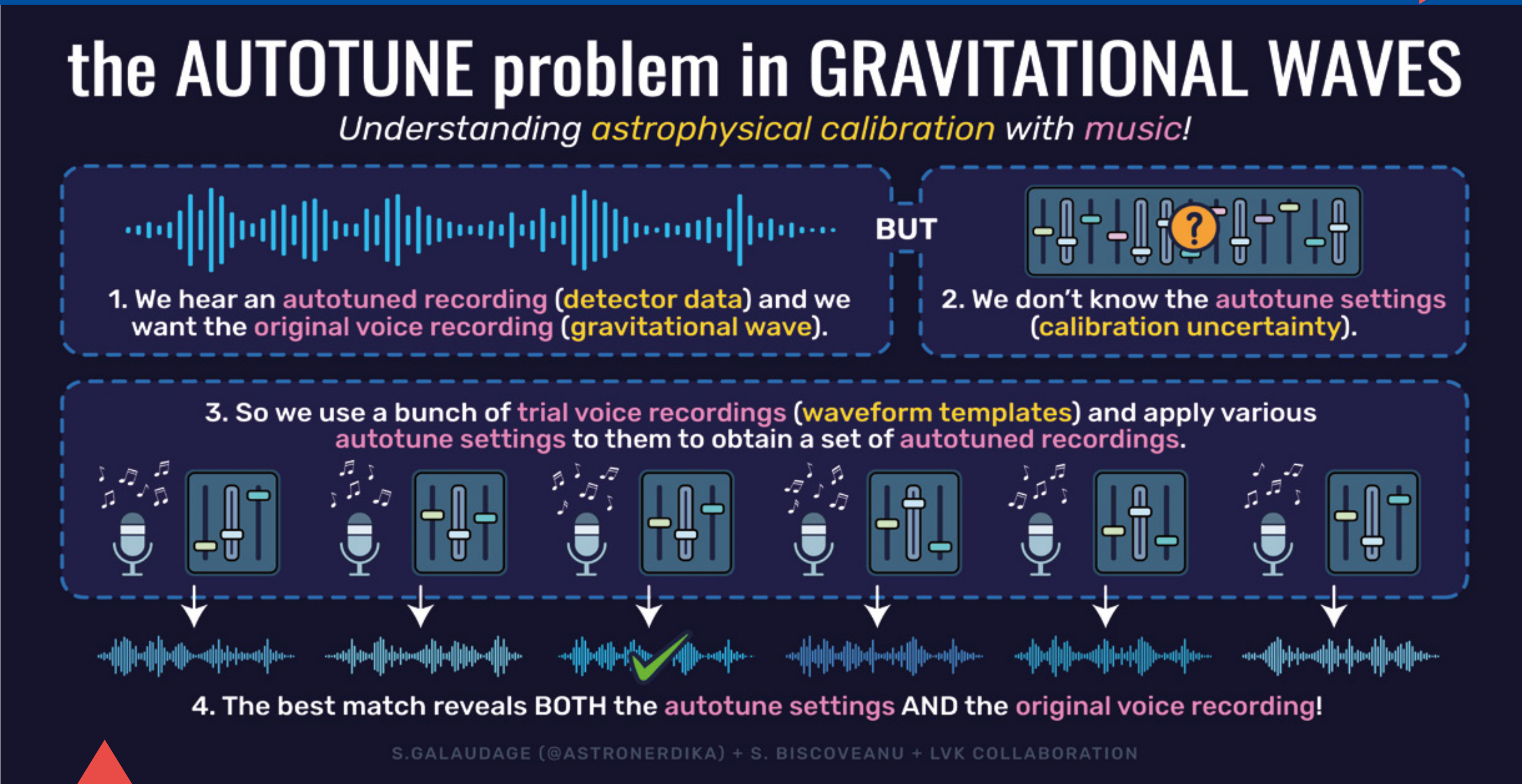
is a faculty member at the Australian National University's Centre for Gravitational Astrophysics, where she studies gravitational-wave astrophysics and detectors. When not thinking about spacetime, she enjoys running, has completed laps of both LIGO "L"s, and is happily ruled by her tabby cat.

Christopher Berry

is a senior lecturer at the University of Glasgow's Institution for Gravitational Research, working on gravitational-wave data analysis and understanding the population of black holes and neutron stars. When not doing science, he enjoys relaxing strolls to visit the local ducks.

* *Parameter estimation means analyzing a gravitational-wave signal to infer the properties of the astrophysical source, such as the masses of the black holes and their locations in the sky (see the back cover of LIGO Magazine issue 7).*

by Ling Sun & Christopher Berry



Using music to understand astrophysical calibration.

Then came the detective work: calibrators and analysts across time zones taking turns with suspicious plots, calibration checks, reruns, discussions, and derivations. The culprit was not the black holes, but a mismatch in how the LIGO calibration team and the parameter-estimation codes were defining uncertainties. This mismatch had gone unnoticed for years. The Universe had not only provided us with a new way to calibrate our detectors, it helped us fix our codes too!

Gravitational-wave 'autotune'

GW240925 showed we could measure the detector calibration from a sufficiently loud gravitational-wave signal. What at first seemed like bad timing actually turned into a wonderful opportunity. It has long been suggested that astrophysical calibration of our detectors should be possible, and here we could demonstrate its usefulness.

Calibrating a detector with a binary coalescence signal works because we know how the chirp should behave. We know how it should sweep up in frequency, and how it should peak in amplitude. This means that we can use one part of the signal to check the consistency of another. This is similar to how autotune is used in making music — you know what each note in the song should be, so you can shift them up or down in pitch if needed. In our case, we could also check the LIGO-Hanford signal against those recorded by LIGO-Livingston and Virgo. This makes it easier to notice when one is out of tune.

GW240925 gave us confidence that astrophysical calibration works. What we hadn't expected was that we would need to use it again so soon.

Another chirp out of tune

GW250207 happened when Hanford was just starting to observe and not all our calibration measurements had come online. The only way to reliably use Hanford data was to once again rely on astrophysical calibration.

Ignoring calibration uncertainty could have led us to the conclusion that GW250207 had unusual black hole spins as well as a ringdown which was inconsistent with the rest of the signal. We might even have suspected that the signal was inconsistent with general relativity.

Getting calibration uncertainty correct is important! The ability to use astrophysical calibration is definitely a lifesaver.

Also check out the back cover:this edition's How it Works features the fundamentals of detector calibration!

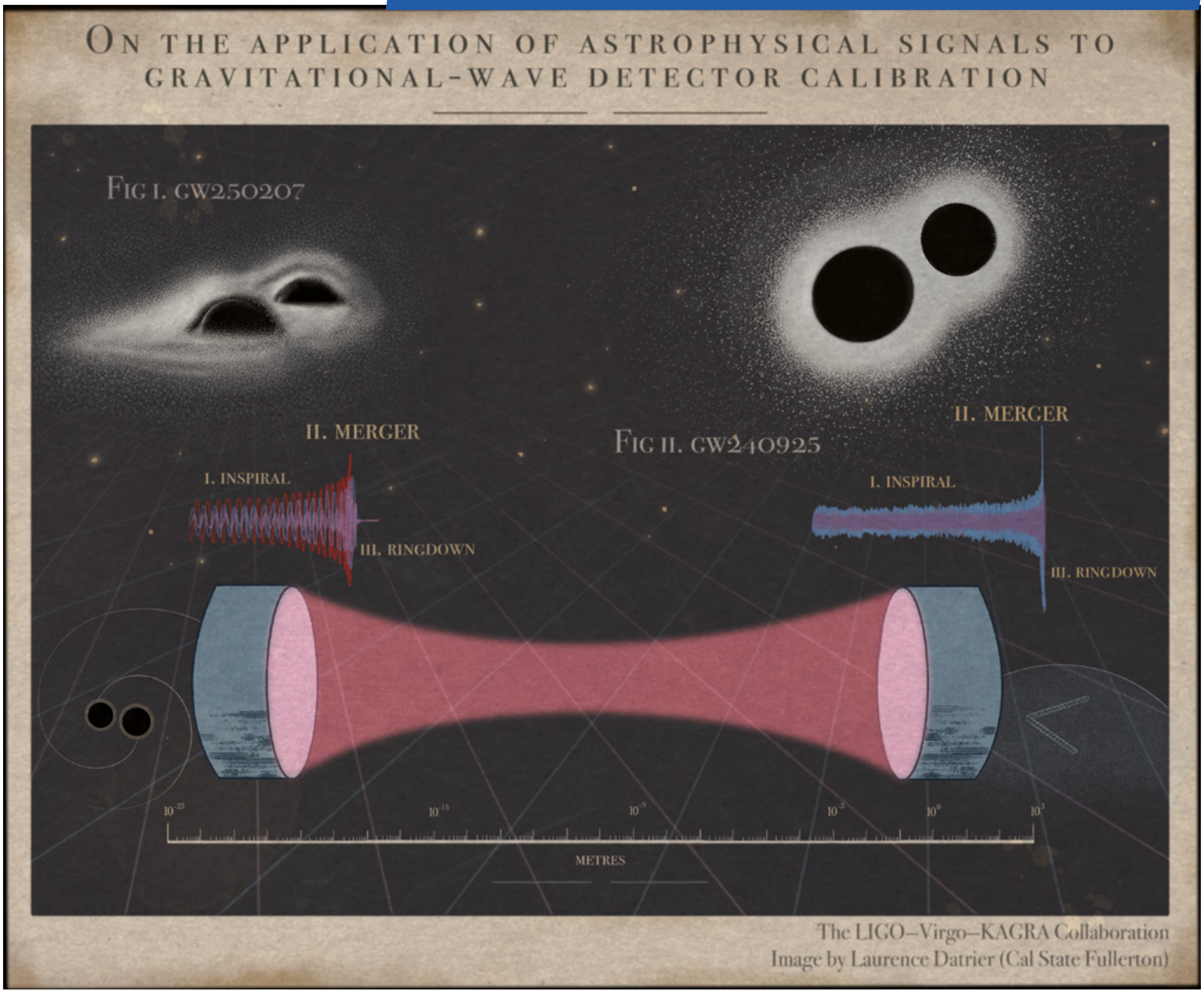
When instrument meets astro

One of the most fun parts of this project was watching detector people and astrophysics people learn each other's dialects in real time. Instrument scientists would talk about response functions, photon-calibrator lines, thermal lenses, and 1-sigma calibration bounds. Astrophysicists would answer with sky maps, spin precession, waveform families, and 90% credible intervals.

These sound like different languages. In practice, they are two sides of the same chirp. A calibration error can shift a sky localization, or imitate a subtle physical effect. A loud astrophysical signal can, in return, help diagnose the detector.

This work was a very LIGO-Virgo-KAGRA (LVK) kind of teamwork: plots passed between experts, terminology translated over many conversations, and everyone slowly converged on the same language. To calibrate a detector with a binary black hole merger, you need both the instrument and the astrophysics. "This is actually a really fun project — we should talk to each other more often," said both astrophysicists and instrumentalists. The wonderful science we can produce together is one of the great advantages of working in the LVK Collaboration.

Astrophysical calibration was used for GW240925 and GW250207.



LVK Meeting in Pune: All you need to know

The team at IUCAA is looking forward to welcoming the LVK community to Pune.

We are excited to host the LIGO-Virgo-KAGRA (LVK) collaboration meeting, the biannual gathering of gravitational-wave (GW) researchers from across the globe. It provides an amazing opportunity to discuss the latest discoveries, share best practices, learn about the participating countries, meet new people and have a great time doing activities together!

This September the LVK meeting is at IUCAA in Pune, India. To help make you most of your time during the meeting, this article gives you an introduction to astronomy and GW research, at IUCAA and in India, the LIGO-India project as well as travel tips.

Sayantani Datta

is a postdoctoral fellow at IUCAA working on waveform modelling in alternative theories of gravity and precision tests of general relativity. When she's not busy with black holes, you'll probably find her painting in oils or digitally, or jamming to Bengali folk and classical songs.

Shubhagata Bhaumik

is a postdoctoral fellow at IIT Bombay, where she works on investigating signatures of orbital eccentricity in gravitational-wave signals. She enjoys cooking, playing the guitar, and is passionate about engaging in spirited discussions on a wide range of topics, from current politics to poignant song lyrics.

The venue: Inter-University Centre for Astronomy and Astrophysics (IUCAA), Pune

Founded in 1988, the Inter-University Centre for Astronomy and Astrophysics , was envisioned by Profs. Jayant Narlikar, Naresh Dadhich and Ajith Kembhavi as a premier institute for astronomy and astrophysics. Since the start, a core part of its mission has been to promote research and education in these fields by fostering strong collaborations with universities across India through its vibrant academic and visitor programmes. Over the years, IUCAA has emerged as a leading institution with research spanning high-energy astrophysics, cosmology, galaxy formation and evolution, extragalactic astronomy, solar and stellar physics, observational astronomy and instrumentation, general relativity (GR), and GW astronomy.

The venue ...

IUCAA is one of the nodal institutions driving the LIGO-India mega-science project, which will set up a LIGO detector in India as part of the global network of GW observatories. The institute plays a key role in providing scientific leadership, conducting site selection and surveys, developing efficient data analysis techniques and computational infrastructure, and facilitating human resource development through specialized workshops and training programmes. Currently, IUCAA hosts the Sarathi Cluster which is a part of the LIGO Data Analysis System (LDAS), providing a peak theoretical computing performance of approximately 535 TFlops to support GW research at IUCAA, its collaborating institutions, and universities across India. IUCAA also serves as a national hub for capacity building and public engagement in GW science. The institute regularly organizes schools, workshops, and hands-on training programs on GW instrumentation, data analysis, and scientific computing for students and early-career researchers, while also conducting outreach lectures, public demonstrations, open-data workshops, and science communication initiatives that bring the excitement of GW discoveries to the broader community!

GW Research in India

The LIGO India Scientific Collaboration (LISC)

Long before our current GW detectors were constructed, pioneering theoretical work in India laid the groundwork for the field. In the late 1980s-1990s, Prof. Sanjeev Dhurandhar and his group at IUCAA developed the foundational matched filtering technique that serve as a backbone for current modeled searches, while Prof. Bala Iyer at Raman Research Institute led the efforts to develop accurate post-Newtonian waveform templates that eventually led to the historic first detection in September, 2015!

by Sayantani Datta and Shubhagata Bhaumik

Building on this legacy, the IndIGO (Indian Initiative in Gravitational-wave Observations) consortium formed in 2012 and joined the global GW network as LISC in 2019. LISC now comprises 17 member institutions with over a 100 members, and the GW community continues to grow across India.

Research at LISC

Throughout the four LVK observing runs, LISC members have played a leading role in theoretical and data analysis contributions.

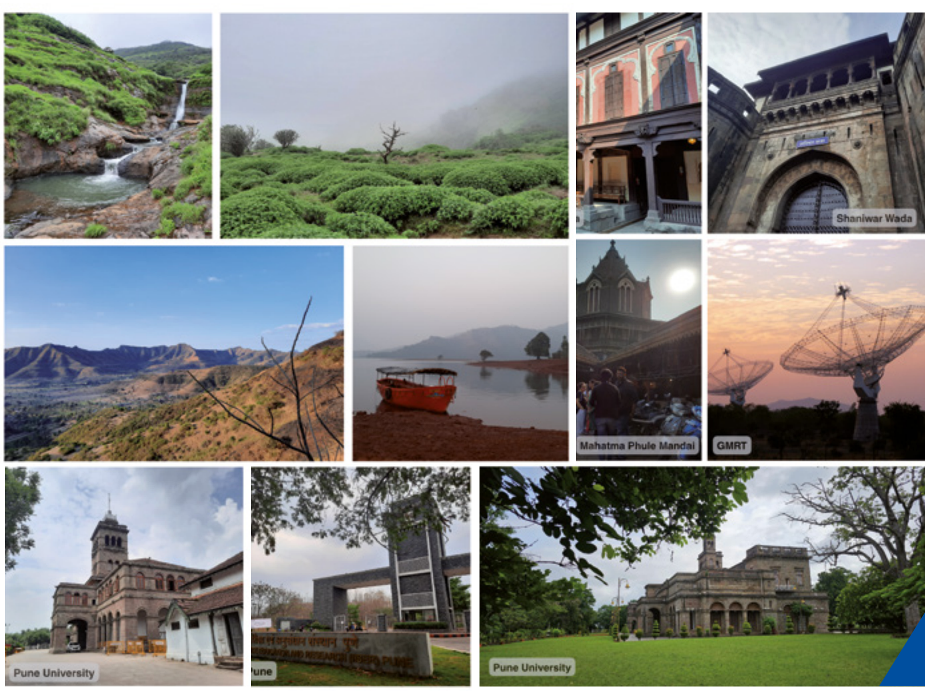
At the International Centre for Theoretical Sciences (ICTS – TIFR*) in Bengaluru and IIT Madras, researchers lead pioneering work in developing Post-Newtonian and Numerical Relativity Waveforms for complex binary black hole systems with eccentricity and precessing spins. The IIT Bombay group has been actively leading low-latency and offline searches since the second observing run, across modeled and unmodeled search regimes, introducing innovative machine learning applications to improve searches. IISER Kolkata has played a major role in detector characterization, optimization of template-based searches, and tests of GR. At the Chennai Mathematical Institute (CMI), researchers work on tests of GR and alternative theories of gravity using GW observations. At IUCAA, GW research covers almost every stage of the scientific pipeline, from detector instrumentation and characterization to extracting astrophysical and cosmological insights from compact binary coalescences, continuous-wave sources, and the stochastic GW background. The research groups contribute actively to waveform modelling, GW searches, parameter estimation, precision tests of GR, studies of extreme matter, gravitational-wave lensing, multi-messenger astronomy and cosmology, alongside developing advanced simulations and noise mitigation techniques for present and future detectors.

Long before our current gravitational-wave detectors were constructed, pioneering theoretical work in India laid the groundwork for the field.

On the instrumentation front, ultra-high vacuum systems, beam tubes, and associated chambers for the LIGO-India detector are being developed at IPR (Institute for Plasma Research), while design and testing of key laser and optical components for those setups are being led by researchers at RRCAT (Raja Ramanna Centre for Advanced Technology).

The strategic geographical placement of the upcoming LIGO-India detector at Hingoli provides a critical science case for the global GW network. By introducing massive new geographic baselines and filling crucial orientation blind spots, LIGO-India will improve the sky localization of GW events by more than an order of magnitude. This precise mapping will be vital for multi-messenger astronomy, allowing telescopes to instantaneously and accurately pinpoint and study electromagnetic counterparts from cataclysmic neutron star and black hole collisions!

For more local information and travel tips, visit: https://www.ligo-india.in/lvk-meeting-pune



Pune is surrounded by beautiful nature and has many places of interest to visit!

ICTS-TIFR is the International Centre for Theoretical Sciences (ICTS), a centre of the Tata Institute of Fundamental Research.

Inspiring the Next Generation by creating opportunities

National Science Week 2024

When people ask me what I do at OzGrav, I often say my job isn't just about communicating science; it's about creating opportunities for people to experience it.

One of my greatest passions has been creating meaningful experiences that connect our researchers with the broader community. Whether it's a child seeing Saturn's rings for the first time in virtual reality, a family building a LEGO interferometer, or someone asking their very first question about black holes, those moments of curiosity have the power to change the way people think about science. I believe the best way to inspire the next generation isn't simply by telling people about discoveries; it's by inviting people to explore them for themselves.

Diana Haikal is OzGrav's Senior Communications and Engagement Lead and co-developer of the OzGrav Ambassador Program. Passionate about making science accessible to everyone, she combines education, storytelling and immersive experiences to inspire curiosity, empower researchers as communicators, and help more people discover the wonders of our Universe.

That belief led Jackie Bondell and me to create the OzGrav Ambassador Program. Instead of a traditional volunteer program, we wanted to build something sustainable that would empower researchers to become confident communicators of their science. Our vision was to equip early-career researchers and postgraduate students with the skills and resources to share their research in ways that are engaging, accessible and meaningful for audiences of all ages.

Our ambassadors complete structured training in science communication, presenting, audience engagement and inclusive practice before representing OzGrav. Today, the program has trained more than 320 researchers, including 30 active ambassadors across OzGrav's eight Australian nodes. Together, they've delivered 94 public engagement events, reached 670 schools, engaged 741 teachers, inspired more than 12,000 students, and engaged over 31,000 members of the public between 2023 and 2025.

One of the most rewarding parts of building the program has been creating experiences that move beyond simply telling people about science and instead invite them to think and work like scientists.

OzGrav Ambassadors at the 2024 Annual Retreat

Ambassador Spotlight: Dr Christine Lee shares her reflections

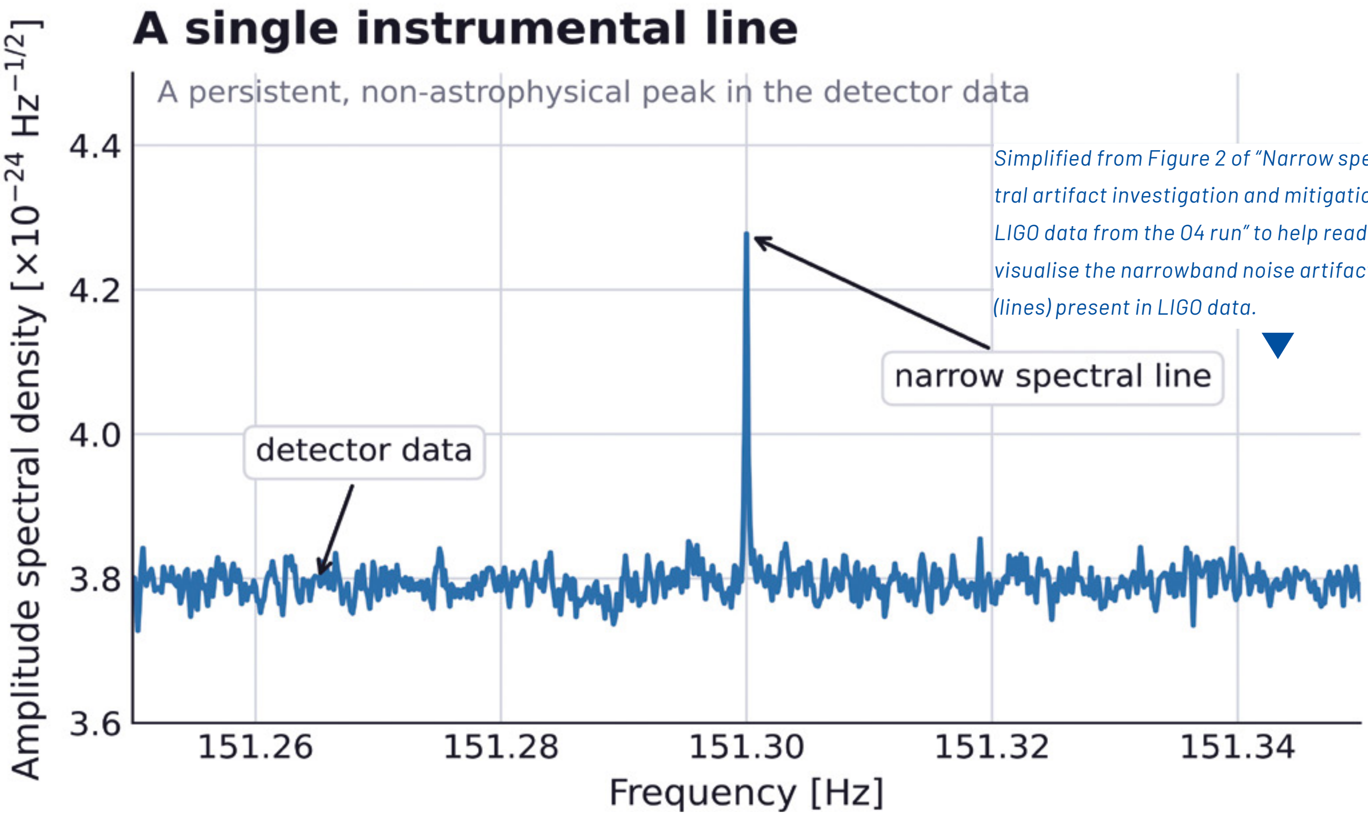
Christine is a postdoctoral scientist at The University of Melbourne and an OzGrav Outreach Ambassador: "In many ways, I am where I am today because of the educators and science communicators who sparked my curiosity. Being able to play a small part in creating that same spark for someone else is incredibly rewarding. I joined OzGrav in 2019, when I was a graduate student. Over the last seven years, OzGrav has provided me with countless opportunities to engage in outreach and science communication. Through initiatives like the Ambassador Program, I have benefited from the abundance of resources and support that have helped me develop the skills needed to convey complex scientific ideas in ways that are accessible and engaging for diverse audiences. More than just a research environment, OzGrav has been a safe and welcoming space, a sanctuary, where I feel empowered to express my creativity and share my passion for science with others. I am deeply grateful for the growth, support, and sense of community that OzGrav has provided throughout my journey."

A flagship example is Mission Gravity, our immersive virtual reality learning experience, which places students in the role of scientists. Using virtual reality headsets or a browser-based version where required, students explore topics including stellar evolution, gravitation, and blackbody radiation. In addition to qualitative observations, students undertake curriculum-aligned investigations, where they collect data, identify quantitative patterns, consider measurement uncertainties, and develop evidence-based scientific models. Students ask questions, gather evidence, test ideas and draw conclusions — following the same process that drives real scientific research. They are guided by OzGrav ambassadors who are researchers themselves, bringing authentic scientific experience into the classroom.

Our goal is to make concepts such as spacetime, gravity, black holes and gravitational waves tangible, memorable and enjoyable for everyone, regardless of age or scientific background. Alongside Mission Gravity, our suite of activities includes LEGO interferometers, 3D-printed models, interactive demonstrations, educational games and tactile learning resources. Each activity is built around a simple philosophy: people learn science best when they are actively involved.

The impact of the program extends far beyond the number of people it reaches. Time and again, ambassadors tell us that presenting to students, answering unexpected questions and sharing their own research has made them more confident communicators and, in many cases, better researchers. I am proud of how the Ambassador Program has grown into a genuine community. Researchers who joined as new ambassadors now mentor others, contribute ideas for new activities and take real ownership of sharing OzGrav's science. What started as an idea has become a culture where communication and engagement are recognised as valuable parts of being a researcher, not something separate from the science itself.

As gravitational-wave astronomy continues to transform our understanding of the Universe, I hope the OzGrav Ambassador Program continues to grow alongside it. Science belongs to everyone, and by helping researchers become confident communicators, we're not only sharing today's discoveries, we're inspiring the people who will make tomorrow's.



Simplified from Figure 2 of "Narrow spectral artifact investigation and mitigation in LIGO data from the O4 run" to help readers visualise the narrowband noise artifacts (lines) present in LIGO data.

Narrowband Noise Impostors in LIGO Detectors

While gravitational-wave detections so far have come from short-lived cosmic events such as merging pairs of black holes, scientists are also searching for continuous gravitational waves: persistent signals expected from rapidly-rotating, non-axisymmetric compact objects such as neutron stars. Searches for continuous waves are hindered by persistent narrowband noise artifacts in detector data, known as "lines". This challenge is addressed through detector characterization.

In a recent paper[1], the LIGO detector characterization group presents the latest tools and methods for investigating and mitigating lines in the LIGO detectors during the fourth observing run (O4). Here, we discuss the impact of lines and the role of detector characterization in continuous-wave searches, as well as the challenges of tracking down and mitigating lines with Evan Goetz, the paper's lead author.

Christine (C): What is detector characterization?

Evan (E): Detector characterization is about understanding the performance of the instrument, beyond just the design noise curve. The design noise curve takes into account the fundamental noise sources, like seismic noise or thermal noise, but often the instruments have additional noise sources that impact the performance. Detector characterization aims to understand the characteristics of the noise, investigate potential noise sources and hopefully help mitigate them.

C: How do lines affect continuous gravitational-wave searches?

E: Lines are typically produced by

[1] *Goetz et al. (2026) arXiv:2606.05959*

monochromatic, sinusoidal noise sources that resemble the quasi-monochromatic continuous gravitational-wave signals we are searching for. Even when the lines don't exactly follow the same pattern as the signal, they can raise the detector noise floor around the frequency of interest, making it much harder to identify a real signal.

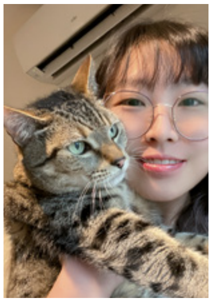
C: How does detector characterization help with these searches?
E: Detector characterization includes the investigation of narrowband noise artifacts that are persistent, or nearly persistent, in the detector and finding ways to mitigate them. Understanding these line artifacts and reducing them as much as possible is key to making continuous-wave detections more likely and more reliable.

A key data-quality product from detector characterization is the "lines list". This is a catalog of known, non-astrophysical lines in detector data, which benefits the downstream continuous gravitational-wave search efforts of the entire LIGO-Virgo-KAGRA collaboration and any external groups using the gravitational-wave detector data.

Evan Goetz

is a research associate at the University of British Columbia and has been a member of the LIGO Scientific Collaboration since 2005. He works closely with the detector characterization, calibration, computing, and continuous-waves groups. Evan has previously co-chaired the LIGO Academic Advisory Committee, the LVK continuous-waves group, and currently co-chairs the LIGO calibration group. He enjoys hiking, camping, snowboarding, and SCUBA diving, and is a pet-parent to an attention-seeking, good-boy orange cat.

Christine Lee



is a postdoctoral scientist at The University of Melbourne. Her research includes the detection of gravitational waves from core-collapse supernovae and glitches from radio pulsars, and she is part of the Detector Characterization Lines Group. Christine also enjoys science communication, performing arts, and answers to a clingy koala disguised as a tabby cat.

During O4, existing detector-data monitoring tools were improved to better track how lines change over time and provide more accurate counts of detected lines, among other enhancements. These tools are not only used to produce the lines list, but also to carry out follow-up investigations of individual line artifacts. Because investigating every line in detail is impractical, priority is given to those most likely to affect astrophysical searches, based on factors such as the detector sensitivity in the affected frequency range and whether the line overlaps with the frequencies of known or expected astrophysical sources.

C: How do line investigations work?
E: We rely on the output of Fscan, a standard Detector Characterization tool for creating spectra, spectrograms, coherence with auxiliary channels to monitor the LIGO detectors on a daily, weekly, and monthly cadence. Using these data products and sometimes bespoke tools, the detector characterization group interprets the output, keeps an eye on any changes, and works with detector commissioners to investigate and mitigate potential noise sources to make the detector data quality as good as possible.

C: Who is involved in these investigations?
E: The team ranges from undergraduate students all the way through to staff scientists and includes LIGO Fellows, who work directly at the detector sites to liaise with commissioners.

In fact, all LVK members are welcome to get involved. Every effort helps, whether it is contributing to lines-list work, getting involved with investigations, or participating in detector characterization activities through weekly meetings and data-quality shifts.

To close the conversation, Evan shares personal reflections on his experience working in detector characterization.

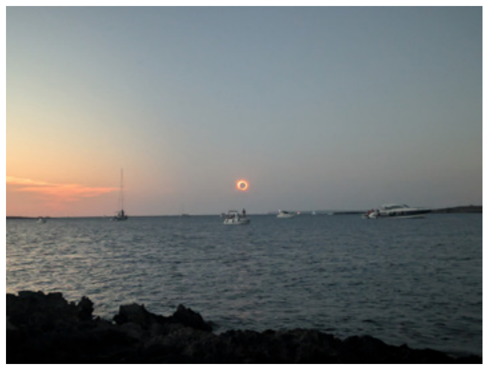
C: What are the open questions in detector characterization?
E: A major challenge in detector characterization is understanding the discrepancy between predicted and measured detector noise. We can model many known noise contributions, but there are still frequency bands where the measured noise is higher than expected. Closing this gap remains a major effort.

In terms of line investigations: although many line sources have been identified, there are still persistent spectral artifacts whose origins are not fully understood. There are also lines that have not yet been fully characterized.

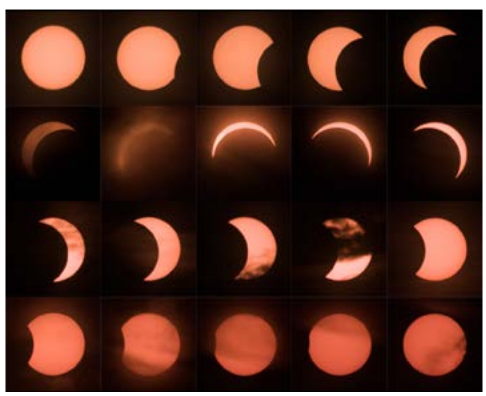
C: What aspect of detector characterization do you find most rewarding?
E: I really enjoy being at the centre of the instrumental work and the data-analysis work. Detector characterization sits at the nexus of many different activities and the work benefits the entire community. The feedback detector characterization provides to commissioners is invaluable, and the investigations we do help improve downstream data-analysis efforts across the collaboration.

It's also an exciting area to work in because there are always new problems to solve. With almost every observing run, there's something new, unidentified, or unexplored, so we constantly get to try new problem-solving techniques.

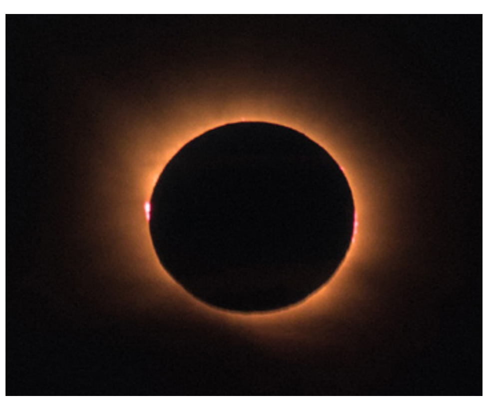
Alicia Calafat, Mallorca



David Keitel, Mallorca



Hannah Middleton. UK



Joan-Rene Merou, Mallorca

A solar eclipse took place on the 12th August 2026 with totality visible from Spain, Iceland and Greenland. It was captured by a few members of our community!

Thomas Sainrat, Spain

Installing LIGO's Bigger Beamsplitter

The bigger beamsplitter and its new suspension were installed inside the LHO vacuum chamber! Ibrahim is inspecting the suspension to ensure everything survived the delicate move.

A major upgrade for the LIGO A+ phase

During LIGO's recently concluded upgrade period, we completed one of the major upgrades planned for the A+ phase of LIGO: installing a brand-new bigger beamsplitter optic. At 45cm in diameter, this new beamsplitter is 22% bigger than the original optic. This provides a larger clear aperture for the main laser beam to pass through, reducing the amount of clipping the very edges of the beam experience. The old beamsplitter blocked only 0.06% of the beam, however this is enough to limit the efficacy of LIGO's quantum squeezing scheme, which directly impacts the sensitivity of the interferometer at high frequencies, above 100Hz. This is the band where we see the final moments of black hole and neutron star pairs rapidly inspiralling, right before they merge.

Installing a larger and heavier beamsplitter necessitated a new, larger suspension system to hold the optic, control its position, and isolate it from vibrations in the surrounding

Tom Roocke is a PhD student from the University of Adelaide, Australia, working on low noise electro-optic sensing and control schemes for the LIGO gravitational wave detectors. Outside of the lab he is eternally tinkering with anything he can get his hands on, from cameras and old speakers to ceramics.

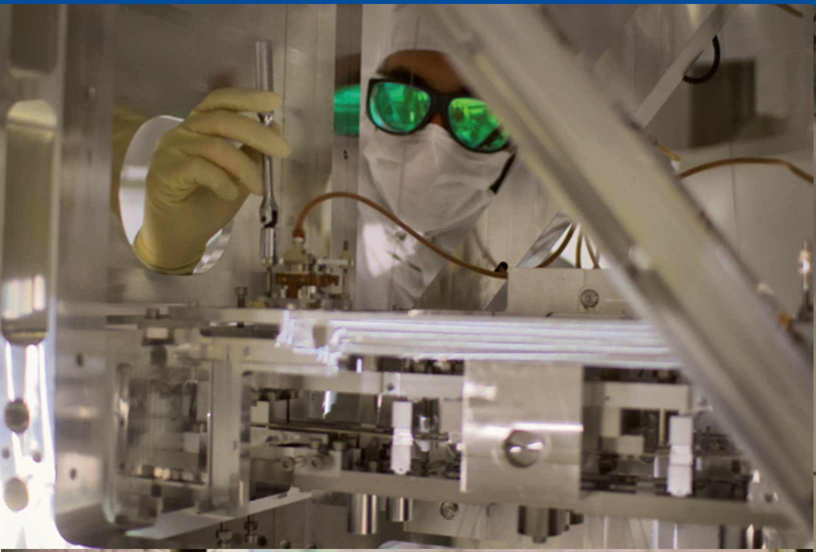
environment. This also presented an opportunity to use improved sensors on the suspension, which is what brought me (and my camera!) into the installation team this summer. These new sensors, dubbed the QOSEMs (Quadrant Optical Sensor and Electro-Magnetic actuator) will reduce the minute swinging of the optic, which contributes to the noise of the detector at low frequencies.

The upgrade took place over many years and countries. First, the optic was cut in Germany by Heraeus before it was polished in the USA by Zygo, and finally coated at the Australian National University. In parallel, the suspension system was designed and tested at RAL (Rutherford Appleton Laboratory) by the UK collaboration before the production versions were built at the LIGO sites.

This all culminated in a rapid effort to install this new optical system into the detectors at the beginning of 2026, taking just over two months, with work from dozens of site scientists and engineers. First, the entire optical table was craned from the vacuum chamber with the old beamsplitter still attached. Placed next to the vacuum chamber, the bigger optic and suspension were then swapped onto the table and thoroughly checked and tested before it was all craned back in.

As of August 2026, LIGO is pumping down the vacuum system, and we eagerly await to see the performance of the new, bigger beamsplitter!

Deon, Ibrahim, Tom (left to right), with the now in vacuum chamber bigger beamsplitter, after inspecting the optic for scratches and dust.



Top left: *Tom adjusting the alignment of a QOSEM on the Bigger Beamsplitter Suspension. Out of picture Oli is checking the readings from the sensor, helping guide it into position.* ***Bottom left:*** *Ibrahim and Tom placing rubber earthquake stops on the beamsplitter, desuspending the optic and preventing it from moving during its craning into the vacuum chamber.* ***Right:*** *TJ installing a protective metal cover in front of the beamsplitter optic, to prevent any accidental knocks or scratches while working on the suspension system above.*

The bigger beamsplitter, along with its suspension and optical table being craned back into the vacuum chamber at LLO. A white cloth covers the suspension to prevent it from collecting dust. People inside the vacuum system are ready to guide the suspension into place.

LAAC Corner: Thesis Writing

Often, the whole process of doing a PhD is referred to as 'writing your PhD thesis', while in practice, the actual writing is a rather small part of the whole adventure. But how long does the writing really take? How much work will it be? And when should you start writing? Of course, there is no answer which works for every single one of you. Therefore, we asked our LIGO Scientific Collaboration colleagues to tell us about their experience and expectations with their own thesis - and we received 45 responses from 10 different countries, of whom about half have completed their thesis, while the other half are still due to finish.

Writing duration & timing

What we were interested in first was `How many months of full-time writing did it take to write your thesis? (If part-time, please state the full time equivalent.)"

On average, our 23 respondents with a finished thesis did **5.5 months** of full time writing - with the answers spanning from 1 - 24 months.

Of our 22 respondents, who have not yet finished their thesis, one-third don't know how much time they will have for writing. The average expected time of the remaining two-thirds was **4.9 months** - which is surprisingly similar to the result from the group who finished.

When is actually a good time to start writing? Alexandre Göttel, who submitted his thesis in 2022, recommends: "Start writing real chapters as early as you can. Going back to projects from your 1st or 2nd year to write about it means you will waste a lot of time", and many of our other respondents agree.

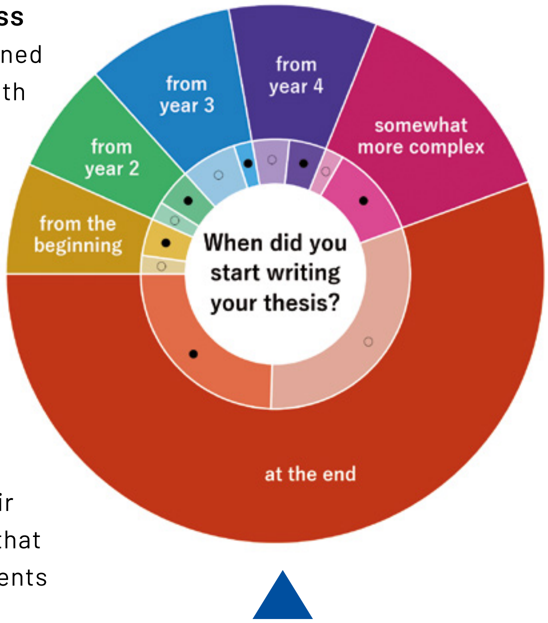
In reality, this is not so easy, though. The pie chart shows the results from all responses: **More than half of our respondents wrote/plan to write their thesis at the very end,** while the other responses are split relatively equally over the PhD duration. A few answers were a bit more complex, though, e.g. regular reports or publications played a role in the writing process.

Support in the writing process

Creative writing is often imagined as a process done in solitude with a cup of coffee. On the other hand, scientific writing, such as journal articles, is regularly a result of multiple discussions and several rounds of feedback. Thesis writing falls somewhere in between. While a PhD scholar may want creative freedom in style and introduction, most seek some support and structure from their supervisors. Our poll suggests that nearly 60% of current PhD students would appreciate one or more cycles of detailed corrections for their thesis chapters. Even though this was not always available from their supervisors, several respondents from the "finished theses" group reported that their peers and other colleagues in their research group were able to provide constructive feedback.

Thesis submission

Thesis submission deadlines can be stressful, especially when unexpected things happen. Prof. Steven Penn recalls, "During my thesis experiment, the accelerator experienced 3 fires due to aging equipment and our need for high energy. I awoke one night in the trailers at the site to see firemen dragging a flaming transformer out of the building. Writing your thesis may require a great deal of patience and resilience, but these are good skills to learn." Several other respondents recounted difficulties that arose during their thesis writing process that they had not anticipated.



When did you start thesis writing? Responses from 45 people; closed circles = finished theses; open circles = not yet submitted theses/writing plans.

The final few months of thesis writing can be the most daunting due to the pressure of PhD contract ending and working on job applications. Our survey shows that while most of the respondents submitted their theses in time, the motivation was largely due to the funding/contract ending.

Many of the current PhD candidates reported that they are worried about how they would handle the pressures of job applications, finishing their research project, and writing their theses simultaneously. Perhaps finding creative ways to decompress while keeping track of writing helps. From the "finished thesis group", we received several interesting recounts from their writing days, such as:

"I wrote it on trains, buses, planes, cars, in 5 different countries"
– anonymous

"I wrote a short poem on gravitational waves at the beginning of my thesis"
– Divyajyoti

Divyajyoti

is a postdoc at Cardiff University, focussed on parameter estimation and population inference, and especially interested in constraining the star-formation history and formation channels of compact binaries with current and next generation gravitational-wave detectors. She is also one of the LAAC postdoc representatives. In her free time she likes to play chess and sing. On a clear day, you may find her curled up with a science fiction book, overlooking the ocean

Jessica Steinlechner

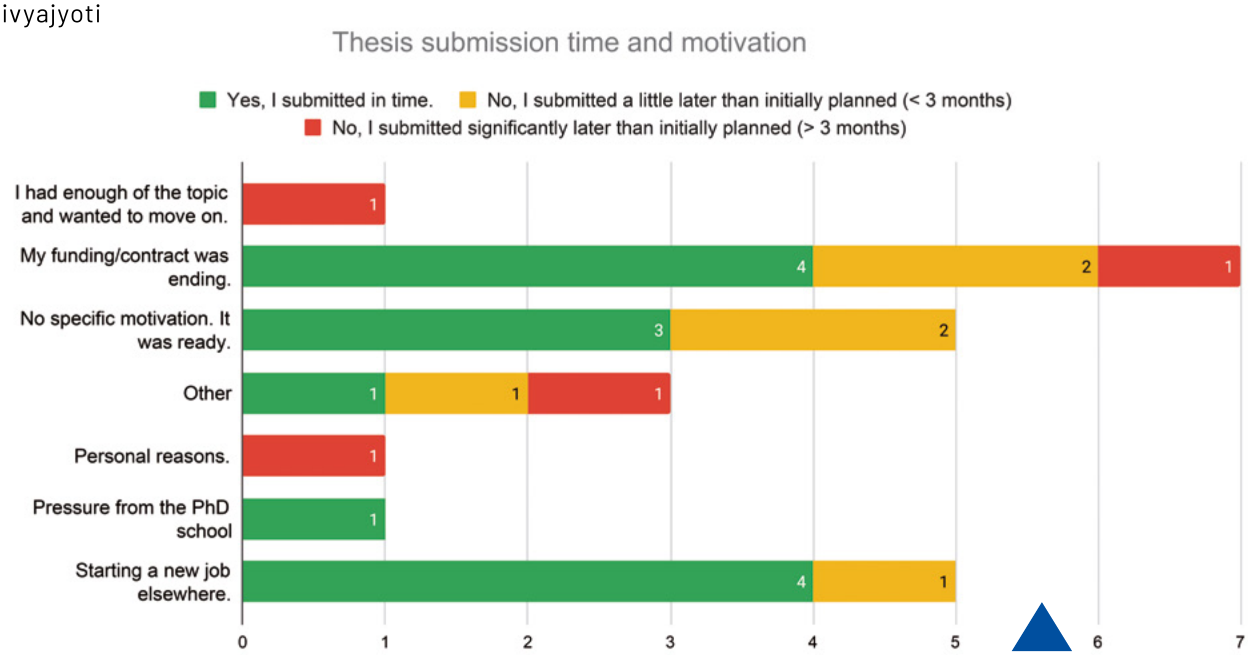
is an associate professor at Maastricht University in the Netherlands. Her research focuses on the development of mirror materials and coatings. She likes drawing, reading and coffee :)

"I took it as a challenge. I used to have a sticky note on my monitor that tells how many days it's been since I started writing." – anonymous

"I love creative writing and I can't really write creatively in scientific publications. I got to do a little bit of that in the introduction, discussing the history of my field in a more poetic way. This was the best (and also my favorite) part of writing my thesis"
– Yi Shuen Christine Lee

Concluding note

At the end of the day, thesis writing is a very personal experience. Eungwang Seo, who recently submitted his thesis, summarises it beautifully as, "For most people, writing a PhD thesis is a once-in-a-lifetime experience. I found myself thinking about it in a much more philosophical way than I ever did when writing papers."



Did you submit your thesis on time? Responses from 45 people along with factors that motivated their schedule.

From Mallorca to LIGO Hanford: Three months as LIGO Fellows

The full moon above Rattlesnake Mountain early in the morning on the way to LIGO Hanford.

Some days began at Roscoe's Coffee – familiar to many people working at LIGO Hanford – before the road slowly left the Tri-Cities behind and entered the flat shrub-steppe of eastern Washington. The landscape opened into dry grass, low bushes, tumbleweeds, power lines, a sign with bullet holes and long stretches of road. Rattlesnake Mountain stayed on the left and, sometimes, the full moon was still hanging above it. On clear days, the snowy peak of Mount Rainier could be seen in the distance. What we noticed most was the horizon: so wide that the clouds seemed to arrange themselves in distant layers, making the sky feel larger and deeper than we were used to. As we got closer to the Observatory, the white plume from the Columbia Generating Station, the nearby nuclear power plant, rose into the sky like a cloud-making machine. And then the sign for the LIGO Hanford Observatory (LHO) appeared by the roadside, a welcome marker in a place that would otherwise be surprisingly easy to drive past.

This was our first time at LHO as fellows for a three-month research stay. We knew we were arriving at one of the most sensitive instruments ever built, but what impressed us was how naturally that sensitivity appeared in ordinary details. The carpets, the isolated infrastructure, the electric cars with strict speed limits along the detector arms and even the way people move through sensitive areas all pointed to the same idea: almost anything can become a noise source. At LIGO, quietness is engineered.

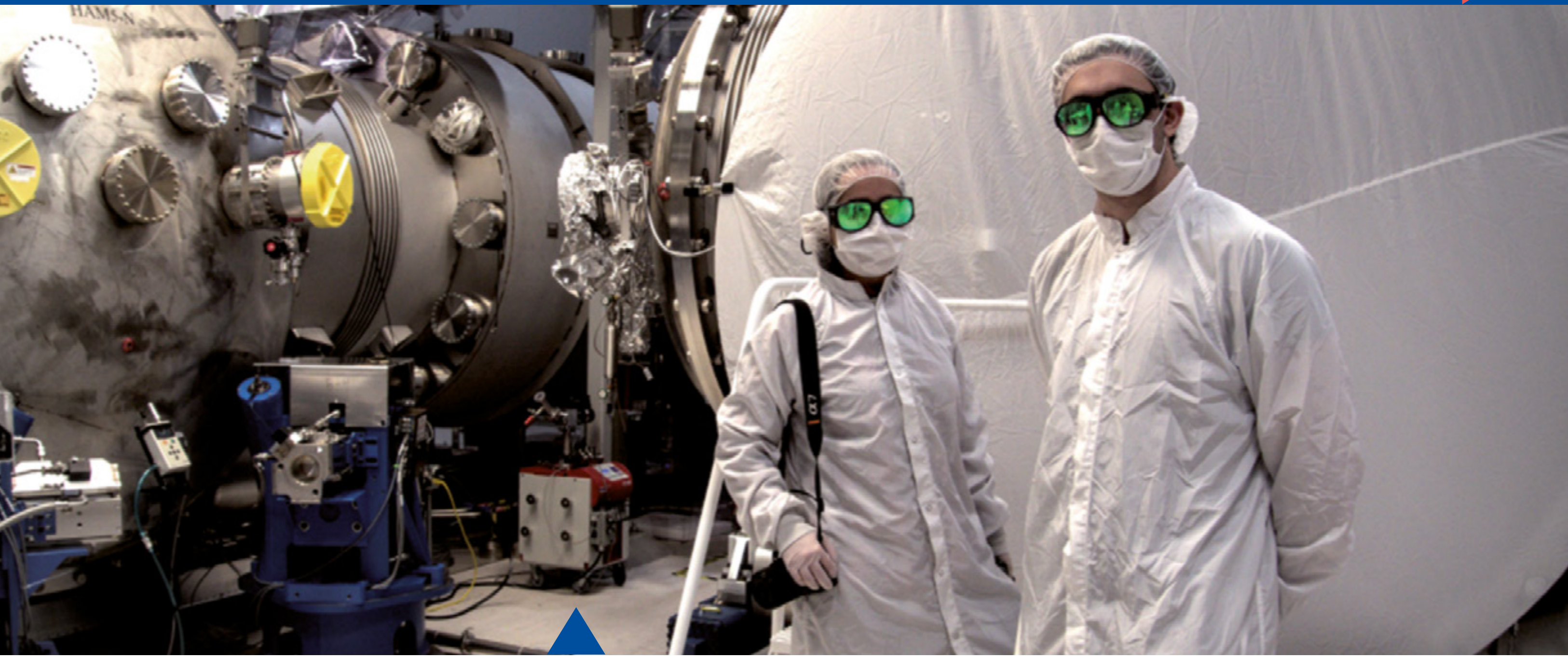
The second surprise was how alive the site was. LHO is not only

Alicia Calafat

is a PhD student at the University of the Balearic Islands, Mallorca, working on gravitational lensing of continuous gravitational waves, detector characterization and machine learning. When she is not chasing gravitational waves, she can usually be found behind a camera, lost in a book, at the cinema or trying to keep her violin in tune.

Joan-René Mérou

is a PhD student at the University of the Balearic Islands, Mallorca, working on continuous gravitational-wave searches, detector characterization and EMRI data analysis for LISA. In his spare time, he enjoys judo, photography and the purring company of three cats.



Alicia Calafat and Joan-René Mérou beside the HAM7 vacuum chamber at LIGO Hanford.

a detector in the shrub-steppe. It is also an ecosystem. During our stay, we learned to share the place with coyotes, ravens, a porcupine, rattlesnakes, crickets, elk and black widows. The wildlife became part of the experience of working there, together with the dry cold, the familiar road in and the candlelight sunsets spreading across the wide sky. Little by little, these details became part of the rhythm of the stay, together with the daily work, the people we met and the routines that slowly made the site feel familiar.

Our days at LHO took shape between the fellows' office, the control room, visits to the large hall known as the LVEA, which houses key laser equipment and some of the detector's vacuum chambers, and many hours spent with internal logs, channels, spectra and conversations that helped connect what we saw in the data with the instrument itself. Detector characterization often felt like detective work. It means identifying what in the data is not astrophysical, finding out where it comes from and proposing a mitigation strategy. A line in a spectrum, a repeated pattern or a pulse could become a clue. Following that clue meant moving from a plot to the data channels behind it, and from there to the hardware, environment or operational conditions that could explain its physical origin.

During the stay, we worked on three main projects, each following a different kind of clue in the data. The first was a repeated pattern of noise lines in Hanford data, with two families spaced about 30 Hz and 100 Hz apart. Using magnetic-field sensors, we traced the 30 Hz pattern to the power supply of video cameras monitoring the laser enclosure. When the cameras were turned off, this pattern disappeared, while the 100 Hz pattern remained, indicating a different source. The second project followed additional lines around the violin modes, sharp resonances produced by the mirror suspension fibers. We tested whether these lines resulted from intermodulation, in which signals at different frequencies mix in a nonlinear system and produce new frequencies. A simple model reproduced some of the lines but did not identify the source of the nonlinearity, which we are still working to understand. In the third project, we studied pulses produced during lock losses, when energy stored in the arm cavities is released within milliseconds and sharply increases the optical power reaching the output photodetectors. By examining how LIGO's fast shutter responded during these events, we gained insights that could help improve future designs.

Alongside these projects, we joined scientists around the world in taking eight-hour on-call shifts, ready to respond whenever a possible gravitational-wave event was identified.

The careful work of many people

For each candidate, our team had to decide whether the public alert should go ahead or be withdrawn. One candidate, S251112cm, was especially exciting because one of the merging objects may have been lighter than the Sun, suggesting an origin beyond ordinary stellar evolution.

Outside the detector, the stay became a collection of shared memories. We explored places around Washington, watched the northern lights, shared meals and celebrations, and built small routines that slowly made the Tri-Cities feel more familiar. We were lucky to share those months with wonderful flatmates, who made our time there feel much warmer.

We returned to Mallorca with a better understanding of the detector and its data, but also with an appreciation for how much we had learned from the way work was shared at LHO. We were welcomed by people who were generous with their time and expertise. This made the environment not only friendly, but extremely productive. When people love what they do, they become deeply knowledgeable about the problems they work on, and for someone new this is among the best ways to learn. After three months at LHO, the data no longer felt like something that arrived from far away. It carried with it a road through the shrub-steppe, a wide horizon, a control room, conversations and a detector kept quiet by the careful work of many people.

LIGO 2026

Alicia Calafat and Joan-René Mérou at the LIGO Hanford Observatory entrance.

Celebrating Diwali together at the fellows' apartment after making a rangoli, a traditional floor pattern made as part of the celebrations.

Am I an experimental physicist now?!

A few weeks ago, I saw my first product launch into the wild. Over the course of a year, a fun idea and a few experiments turned into a Real Thing (that we call Generative Instrumentation). These days I spend a lot of my time working with designers, software engineers, marketing teams, as well as our customers. I create products that use agentic AI to turn a plain-language description of a scientific instrument – a spectrum analyzer, lock-in amplifier, matched filter – into a working, tested piece of digital hardware.

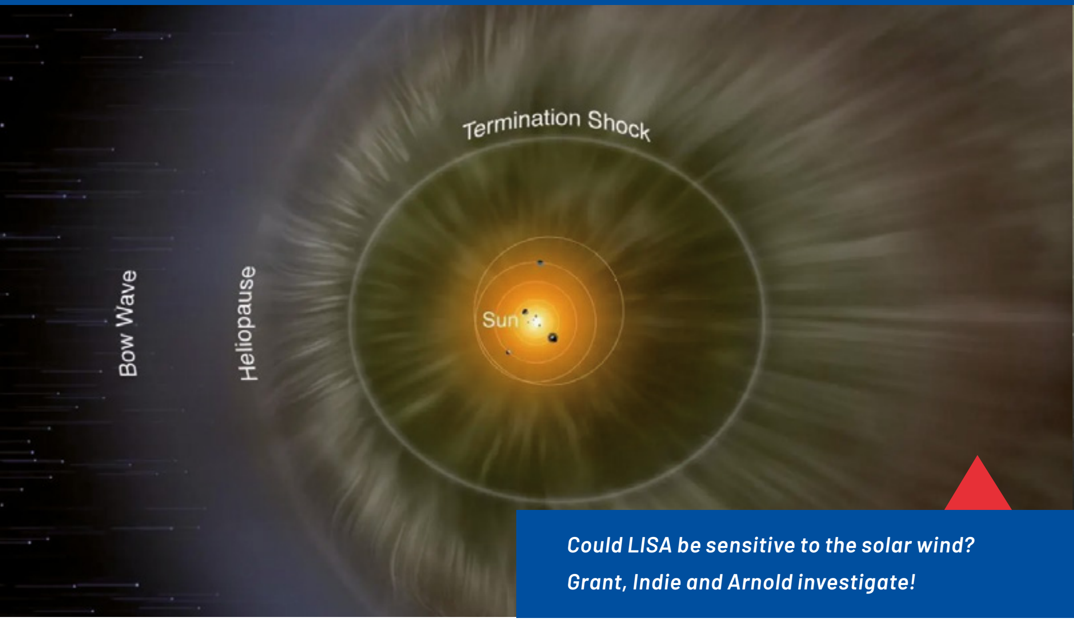
Rory Smith is an AI and Engineering lead at Liquid Instruments, a Canberra-based startup making reconfigurable scientific instruments. He enjoys traveling, cooking, and in his advancing years, playing folk music at Melbourne's finest dive bars and festivals.

I work for a company called Liquid Instruments as their Lead AI Instrumentation Engineer. Some of you may have heard of the company. The origin story goes that an Australian National University (ANU) physics professor and a handful of PhD students and post-docs built a piece of reconfigurable test-and-measurement hardware in a basement stairwell under the physics labs, while they were working on LISA and LIGO instrumentation. Today we are a 100ish-person, series-C startup based in Canberra, with offices in Melbourne and San Diego. So as far as LIGO departures go…not that far from where I started. Except day to day it is!

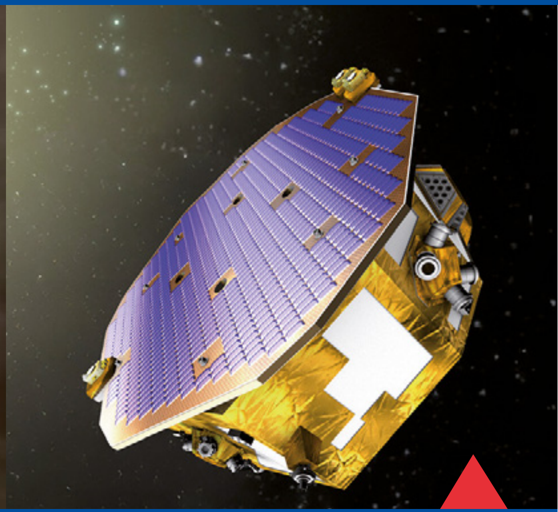
I enjoyed a lot of aspects of work in LIGO, and astrophysics more broadly. But after more than a decade I came to see my work as less fun and more routine. Some things were incredibly exciting – the first observations of gravitational waves are objectively awesome(!) – and I loved the collaborative nature of the work, plus all the travel. But there's only so much one can know about binary black holes.

In contrast, I love the pace of a startup. Ideas bounce around fast, prototypes get built and scrapped in days, and people from sales and the executive side pitch in frequently with ideas based on what customers and the business actually needs. A small village then turns ideas that survive into a product. If you're not an expert on a particular thing at the beginning (I had never heard of an FPGA before I started, nor knew anything about hardware languages), you will be very shortly.

Moving out of academia was harder than I expected, and the job market isn't making it easier. I was lucky enough to spend a few months traveling while I looked for work, which I found was great for perspective. And if you're weighing it up: LIGO scientists are more skilled and creative than the process tends to make you feel; networking really is as important as everyone says; the right job takes time to find; and so on. There's lots of fun, creative work out there.



Could LISA be sensitive to the solar wind? Grant, Indie and Arnold investigate!



LISA Pathfinder placed two test masses in a nearly perfect gravitational free-fall.

LISA Pathfinder Persists in Discovery

Moving to Los Alamos National Laboratory (LANL) to forecast the solar wind (LIGO Magazine issue 19, page 25; 2021), I hoped to reconnect with gravitational-wave astronomy. In early 2022, I was inspired by Smetana's 2020 MNRAS and Frank, Piotrzkowski, Bolen, Cavaglià and Larson's 2020 CQG papers to ask whether Laser Interferometer Space Antenna (LISA) might be sensitive to time variation in the solar wind's charged particles.

Grant David Meadors

is a scientist at Los Alamos National Laboratory and a former member of the LIGO Scientific Collaboration. He enjoys exploring volcanic mesas and hot springs with his husband and coming home to their friends and two cats.

LISA Pathfinder (LPF) made this question answerable. LPF, flown from 2015 through 2017 at the Earth-Sun Lagrange Point L1 to test LISA technologies, succeeded "with flying colors", and its data was open. Everybody helped, from the Frank et al authors, along with Ira Thorpe and Jake Slutsky at Goddard and my space-weather colleagues, Nick Arge, Shaela Jones, Carl Henney. I turned to high-school students Indie Desiderio-Sloane and Arnold Yang at the Institute for Computing in Research (ICR), where, in 2021, Lexi Smith and Shira Goldhaber-Gordon had re-implemented neural networks for continuous-wave searches.

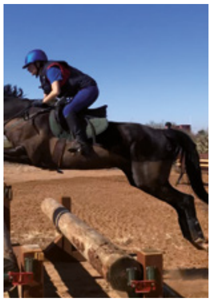
Through our 2025 paper [1], we analyzed LPF together with the Advanced Composition Explorer (ACE), a nearby satellite. Indie and Arnold calculated correlations, coherence spectra, data gaps and simulated excitations for validation, following Frank et al.

We found no signal from solar wind, yet sunlight pressure is believed to be tenfold larger, perhaps only a couple orders of magnitude below the noise. LISA looks safe and probably won't be a serendipitous space-weather instrument.

Solar flares could still impact observatories across the solar system. The Interstellar Boundary Explorer (IBEX) has recorded solar wind echoes reflected from the outer heliosheath! If astronomers ever launch an observatory to the Sun's microlensing line, where gravitational waves could be focused, perhaps they will check the space-weather forecast.

Now Indie & Arnold can share their stories.

Indie Desiderio-Sloane



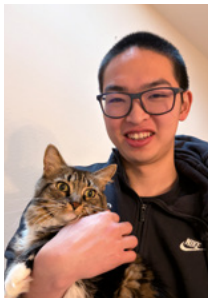
is a senior at the California Institute of Technology, studying physics and currently researching supernovae. She enjoys spending time with her horse, Emmy, baking, and reading when not elbow deep in research.

I took a circuitous route to this research. After learning about the Institute for Computing in Research through a local Linux group, I attended its coding boot camp and was later accepted into the summer research program. I worked with Arnold Yang under the mentorship of Dr. Grant Meadors.

During the month-long program, we made significant progress on our project, attended seminars, and presented our findings to the Institute community. After the program ended, we continued the research with the goal of publishing a peer-reviewed paper. I further developed the project through an independent research class during my senior year, culminating in another presentation.

Our progress slowed as I prepared for and started college at Caltech and Arnold was elbow deep in college applications and as we adjusted to different time zones. Once our schedules stabilized, we completed, edited, and submitted our paper to CQG. I am grateful to Grant, Arnold, and the Institute for making this research possible.

Arnold Yang



Arnold Yang is a Stanford University student building everything from cybersecurity tools to atmospheric research drones. In his freetime, he enjoys soccer, running, painting, reading, and playing chess.

Logging off Mark Galassi's small programming course, I would spend the rest of that night perfecting 'Getting to Philosophy', a script automating the Wikipedia phenomenon of following first hyperlinks to the Philosophy page. Mark, a LANL astrophysicist, taught these biweekly Thursday night courses with a contagious energy. We explored everything from simulating disease infection models to exploring linguistic etymology. They gave me an early sense that programming could explore questions much bigger than the code itself.

Those courses also became a pathway into the Institute for Computing in Research, a community Mark directed, pairing high schoolers with volunteer mentors for hands-on research. Through the Institute, Indie and I were paired with Grant on a project involving what felt like the dream astrophysics project: analyzing satellite data for gravitational-wave research, all set against a New Mexico backdrop shaped by Los Alamos, the Santa Fe Institute, and the history of modern science and engineering.

By the end of the summer, we had initial results, but the project was far from finished. Over the next couple of years, Indie and I returned to the code in bursts. We reopened old notebooks, ran simulations, checked correlations and coherence spectra, and verified our techniques. Sometimes that meant filling gaps in satellite measurements, rerunning the same analysis after one small change, or comparing simulated excitations against our results. The project kept surviving the calendar: outlasting the summer internship, the school year, college applications, multiple rounds of checks, until it finally became a published paper.

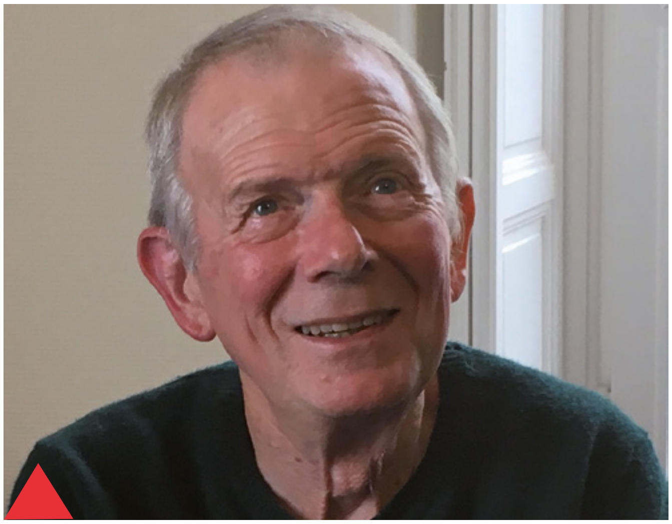
The LISA Pathfinder mission tested the technology required to realise a gravitational-wave detector in space and laid the groundwork for the upcoming LISA mission.*

References:

[1] Yang, Desiderio-Sloane, Meadors, CQG, (2025) doi: 10.1088/1361-6382/adb538

* *Find out more about LISA Pathfinder in our 10 year anniversary article (LIGO Magazine issue 28, p.24).*

Remembering Alain Brillet



Alain Brillet (1947 - 2026).

Alain Brillet, who passed away on 20 March 2026, was one of the two founding fathers of Virgo. He earned his PhD in 1976, then worked in Boulder with Nobel laureate John Hall, where he set the precision record for the Michelson-Morley experiment before returning to France in 1982.

In 1979, Alain Brillet met with Ron Drever and the Garching group who were developing the first interferometer prototypes, and later proposed recycled interferometers. Brillet motivated a group of physicists in France to work on similar interferometers for detecting gravitational waves. He visited Rai Weiss at MIT and, in 1985, he met Adalberto Giazotto, who shared the same interest. Their expertise proved complementary: Brillet specialized in optics and lasers while Giazotto's team worked on the superattenuator system. In 1989 the pair proposed to INFN and CNRS to build the Virgo detector (approved in 1994). In recognition of this achievement, the CNRS awarded Alain Brillet and Thibault Damour its 2017 Gold Medals.

From 1989 to 2003, Brillet first led and then jointly (with Giazotto) directed the consortium formed around Virgo near Pisa. Their tenacity was notable given that much of the scientific community initially viewed frontier research with skepticism. From 2008 onward, he turned his focus to the optics and laser system design of Advanced Virgo, the next-generation detector.

– Marie Anne Bizouard

Remembering Andrzej Trautman

Andrzej Trautman (1933 - 2026)

Professor Andrzej Trautman was one of the pioneers of modern general relativity and among the first to demonstrate that gravitational waves are genuine physical phenomena carrying energy and information. His fundamental work in the late 1950s, together with the Robinson–Trautman solutions, laid part of the theoretical foundation that ultimately enabled the discovery of gravitational waves by the LIGO and Virgo collaborations. For more than five decades at the University of Warsaw, he built the Polish school of relativity and inspired generations of physicists. The international scientific community has lost an outstanding scientist, teacher, and visionary whose legacy will endure.

– Marek Demiański

EGO obituary:
https://www.virgo-gw.eu/news/goodbye-andrzej-trautman/

Remembering Mike Cruise

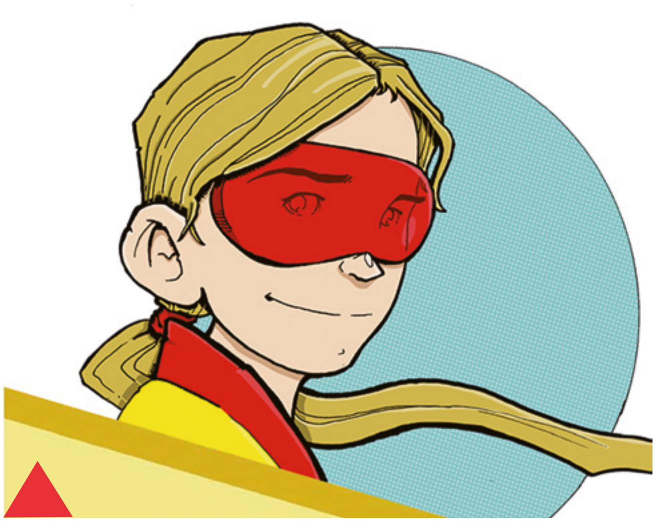
Mike Cruise (1947-2026).

Mike Cruise (1947-2026) joined the University of Birmingham as Professor of Astrophysics in 1995. Already an accomplished space scientist by the time he arrived in Birmingham, gravitational-wave research had been firmly on his radar for some time. His interest initially centred on LISA, and he began developing instrumentation for the LISA Pathfinder mission, but it soon extended to LIGO as well. He joined Jim Hough, Ken Strain, and the Glasgow group in what was emerging as a possible UK contribution to the Advanced LIGO upgrade, which he helped secure. Even after being appointed Pro-Vice-Chancellor for Research, he remained involved in the day-to-day research activities of the Birmingham group until his formal retirement and beyond. Everyone who had the pleasure of interacting with Mike remembers his passion for science, sharp intellect, witty sense of humour, and relentless effort to support young researchers. In 2023, Mike was made an OBE for services to space science.

– Alberto Vecchio

The full version can be read at:
https://www.sr.bham.ac.uk/RememberingMikeCruise.php

Remembering Rebecca Thompson



The LIGO Spectra special edition comic.

I first met Becky as a postdoc at NASA GSFC while she was at APS. We collaborated on a workshop where we strapped accelerometers to teachers, cut in line for rides at the local Six Flags (according to Becky, “For Science!”), and used the data to reinforce physics concepts. She had effusive energy and a singularly nerdy sense of humor. Her comic book series came up in conversation and we knew that LIGO and Spectra were a perfect match. We kept in touch, roped Joey Key into the plan a few years later, and got to work. Becky was one of a kind, is fondly remembered, and will truly be missed.

– Tyson Littenberg

The LIGO Spectra special edition comic can be found in English, Spanish, and Blackfoot at
https://dcc.ligo.org/LIGO-P2400364/public.

Memorial gifts to support Becky's priorities to create opportunities for women and others who have been historically excluded in STEM fields may be made to the fund in her honor at Bryn Mawr College at
https://mawr.life/y94E, or to the Saint Louis Science Center at https://www.slsc.org/join-give/give/.

Obituary:
https://www.legacy.com/legacy/rebecca-thompson

Transforming gravitational-wave detections into musical structure

My first encounter with the idea that eventually led me to LIGO was quite unusual. While on a family vacation, I was working on a haute couture dress for my performances and collecting shells with my aunt, Suely. During one of our walks on the beach, I found a shell whose markings resembled four spectrogram lines. Looking at it, I felt as though I was holding a musical score written by nature itself.

Ana Schurmann

is a composer, singer-songwriter, multi-instrumentalist, innovative designer and researcher whose work brings together music, science, philosophy, fashion, sustainability and performance art. Outside her creative work, she enjoys Kung Fu, dance, swimming, painting, meditation, studying languages,reading philosophy and exploring nature.

At that time, I had been studying vocal spectrograms – visualizations that show how the frequency (or pitch) and harmonics of a voice change over time. As part of that journey, I had recently visited Pinuccio Sciola's Giardino Sonoro in Sardinia – an open-air installation of large stone sculptures that produce musical tones when touched [1].

That shell stayed in my mind long after the vacation. It led me to explore how patterns emerge in sound and nature and, via an extensive project exploring infrasound (sounds below the nominal lower threshold of human audibility) and sound visualisation, eventually to LIGO, Virgo and KAGRA (LVK). A long discussion with the Virgo Brazil team brought me to a question that would ultimately change the direction of my work:

"Can we create a scientific method to decode the universe into the audible range using gravitational-wave detections in harmonic and chronological order?"

That question became the foundation of what is now "The Harmonic Universe (Chirp Symphony)" [2, 3]. Together with physicists Cassius de Melo and Regiley Pimenta (Aeronautics Institute of Technology), we developed a methodology that transforms gravitational-wave detections into musical structure.

We begin with six gravitational-wave detections of merging black holes or neutron stars from the LIGO-Virgo-KAGRA catalog. Preserving the signal's characteristic "chirp", the changing frequency is translated directly into musical pitches and each signal becomes one musical motif within the symphony.

The six motifs are then arranged according to their redshift (a measurement that tells us how far back in the universe's history each event occurred). From the oldest event to the most recent, this sequence shapes both the order of the motifs and the harmony of the symphony. The composition weaves the signals into a single musical journey whose structure is guided entirely by real data from the Universe. For this reason, I often describe myself less as a composer and more as a decoder.

Visiting the Virgo gravitational-wave detector.

I love to collaborate with scientists and these interdisciplinary collaborations form part of a broader initiative referred to as Scientific Music, which seeks to develop reproducible methods for translating scientific data and natural phenomena into musical languages while preserving meaningful relationships with the original data.

The collaboration with members of the LVK community has been extraordinary. Visiting Virgo in Pisa was one of the most inspiring experiences of my career. Seeing the interferometer, the laser systems, the control room, and meeting the scientists who dedicate their lives to understanding these signals gave me a deeper appreciation of the immense human effort behind every detection. I am especially grateful for the support and insights shared by the Virgo and EGO (European Gravitational Observatory) teams, including Vincenzo Napoli and Guglielmo Rossi from the communications and public outreach team at EGO.

Beyond gravitational-waves, I am exploring other scientific datasets. My collaboration with Dr. Kimberly Jameson (University of California, Irvine) explores the work of Concetta Antico, who has been studied for her rare tetrachromatic color vision. We have been investigating methods for translating visual information into sound and exploring whether musical representations can offer new perspectives on tetrachromatic color vision. In Argentina, I am collaborating with biologist Dr. Rosario Jacoby on the analysis of bird vocalizations. With astronomers Ana Clara Rocha and Thiago Flauzino Haber, I am also working with stellar evolution data. The long-term goal is to build an open scientific database that may allow future generations to become "decoders" of patterns across nature and the cosmos.

This year, we performed "The Harmonic Universe (Chirp Symphony)" at the Aeronautics Institute of Technology and in Sao Jose dos Campos alongside a local orchestra and wind quintet, respectively. Next year we will present a new live performance exploring the lifecycle of a star for Astronomy Day at the European Southern Observatory in Chile

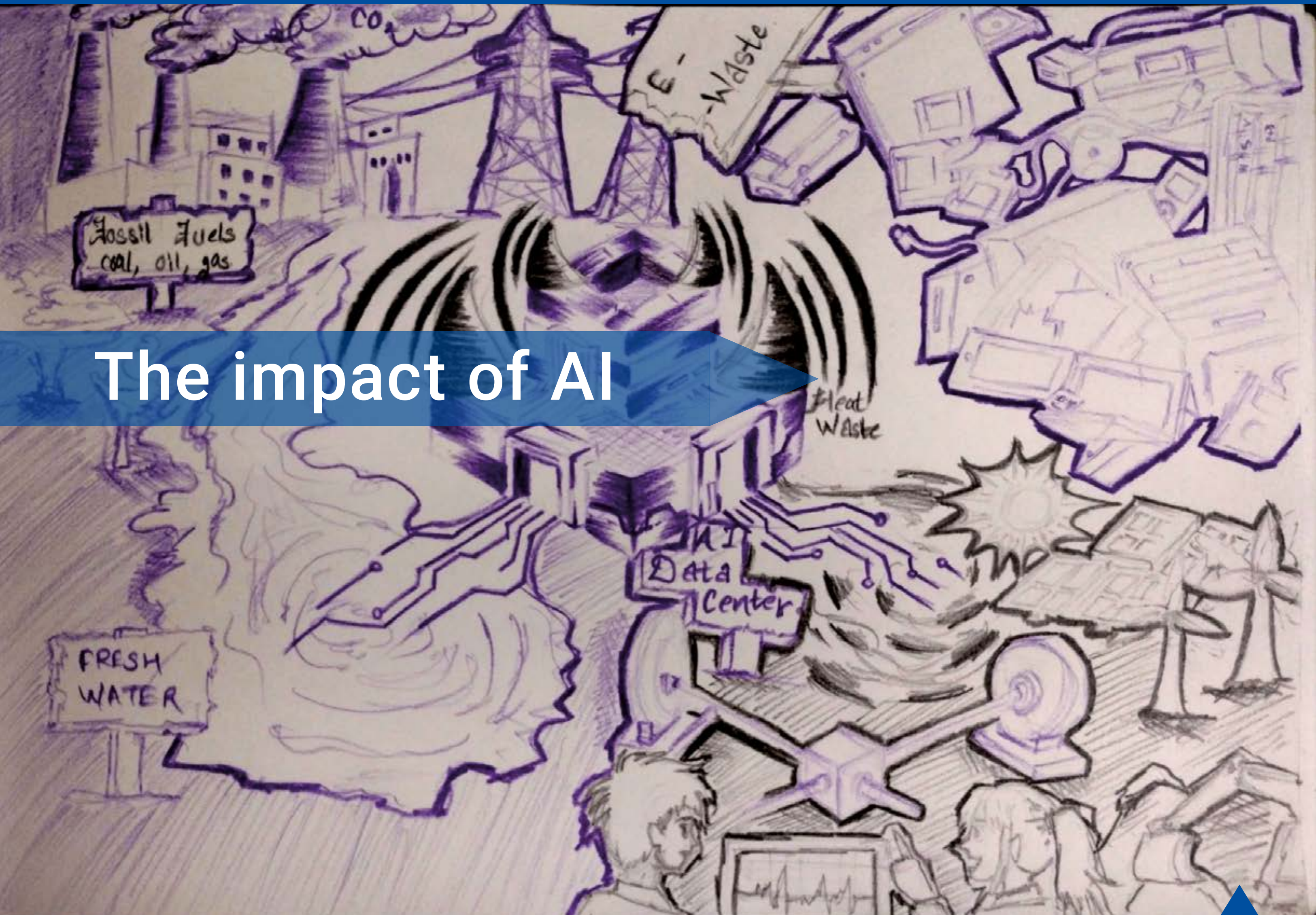
Discovering gravitational-wave science has transformed the direction of my artistic and research life. One of my dreams is to visit LIGO itself one day and it would be an incredible honor to see the observatories firsthand and meet more of the people whose work makes these discoveries possible. My goal is to unite minds and share knowledge.

Pinuccio Sciola's sound garden
[1] https://www.psmuseum.it

The Harmonic Universe (Chirp Symphony)
[2] https://youtu.be/_5VvFpW7Hn0
[3] https://open.spotify.com/track/0Sd9EyZ5ZnaNRl46zEZwmb

A performance of "The Harmonic Universe (Chirp Symphony)" at the Aeronautics Institute of Technology in Brazil alongside a local orchestra.

The impact of AI



How often do we consider the impact of our science on the environment?

As scientists within the LIGO-Virgo-KAGRA Collaboration, we identify and remove noise sources that can obscure the tiny space-time distortions we seek, which, for decades, were deemed impossible to detect. These include ocean waves crashing kilometres away, wind shaking the building, passing trucks, seasonal temperature changes, distant earthquakes, or thirsty ravens pecking at frosty pipes along the detectors' arms.

While we work tirelessly to minimize the impact of the environment on our detectors, how often do we consider the impact of our science on the environment and the noise we create in it?

With Artificial Intelligence (AI) already at the very core of what we do, the question of its environmental impact is becoming difficult to ignore. AI algorithms can classify detector glitches, accelerate parameter estimation, improve detector characterization, reduce computational costs and help identify astrophysical signals in near real time. We increasingly rely on AI for everything from writing papers to finding information to everyday tasks.

Machine learning has transformed the way we search for GWs. However, it comes with hidden operating costs. It relies on data centers filled with processors, storage devices, power supplies and cooling equipment. The cloud, it turns out, is still a very physical place. Every simulation, every training run, every parameter-estimation run and every Google search ultimately consumes physical resources somewhere in the world.

Although estimates are complicated because AI data centers do not publicly disclose the required inputs, reports suggest that AI's power demand is approaching that of the United Kingdom, its water consumption, which is projected to double annually [1], is comparable to the global annual consumption of bottled water and its carbon footprint in 2025 was equivalent to that of New York City [2].

As a community, we routinely discuss CPU and GPU hours, but we rarely discuss water usage or other environmental impacts. AI accelerators depend on rare minerals, complex supply chains, and energy-intensive manufacturing. Due to intense usage, they are often replaced after only a few years, adding to growing electronic waste.

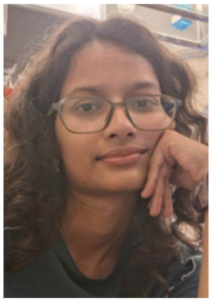
Is AI the Problem?
The answer is not necessarily. The amount of data we collect is growing. Detector sensitivity continues to improve, and candidate events arrive at an increasing rate. Getting the most out of our experiment requires matched-filter searches based on enormous template banks that use expensive numerical simulations. Parameter estimation campaigns can consume weeks of computing time. In many cases, computations replaced by optimized AI workflows reduce energy consumption. The relevant question is then not whether AI consumes resources, but whether it shortens the path to our scientific objectives.

A Path towards GREEN AI.
Worldwide, AI is using more resources and producing increasing amounts of waste. To mitigate this, a new movement known as "Green AI" has begun, where computational efficiency is an achievement in its own right. It relies on sharing pretrained networks instead of repeatedly retraining similar systems, optimizing models with few, carefully chosen parameters, and utilizing computing resources more efficiently.

The challenge is building "green" data centers, while keeping pace. These centers could be greener when water is recycled instead of left to evaporate, waste heat is used to remove carbon dioxide from the air or purify water, and electricity comes from renewable energy sources. Solar and wind farms take up space and consume resources to build, bringing their own environmental costs. New nuclear reactors are being built. Some are designed to burn existing nuclear waste and others that use materials like thorium may in time become economically competitive. Cooling them can be a challenge – as Europe has seen this year.

The rapid growth of the AI sector prevents the adoption of comprehensive legal requirements that protect the environment and ensure transparency and accountability. Most data centers today are tied to the cheapest available power and water sources. This results in increased air pollution and contaminated land and water supplies [3,4].

Sakshi Satish Madekar

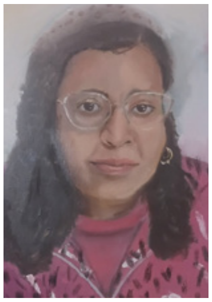


is a PhD student at IFAE: Institut de Física d'Altes Energies in Barcelona and a Marie Curie Fellow. Her work focuses on the intersection of detector characterization and tests of General Relativity. Currently, she is obsessed with maximizing protein in cakes.

Ruxandra Bondarescu

is a Ramon y Cajal fellow and the PI of the Gravitational wave group at the University of Barcelona. Her free time is spent roaming the beaches in Spain or on various river banks in Romania.

Jayashree Balakrishna



is an award winning math and physics professor at Harris-Stowe State University in Saint Louis, USA. She has a strong interest in environmental science, enjoys reading, listening to music and watching movies.

Edward I. Lundgren

is a veteran author and illustrator of books for children, available on Amazon, including "A Child's First Book on Gravitational Waves: You, Me and the Dancing Black Holes". While this fall he is starting his senior year in high school, he prefers rock climbing, hiking and swimming to going to class.

Our scientific collaboration has experience making the impossible possible through GW detection. To map the path towards green AI within the GW community, we must engage in active usage monitoring, environmental monitoring and mitigation of the damage done to the environment. It is important to prevent misleading paths (greenwashing), while continuing to produce high-quality research in a drastically changed scientific environment. This way, we not only reduce the noise in our detectors, but also ensure that we do not create unnecessary noise in the environment we share.

References

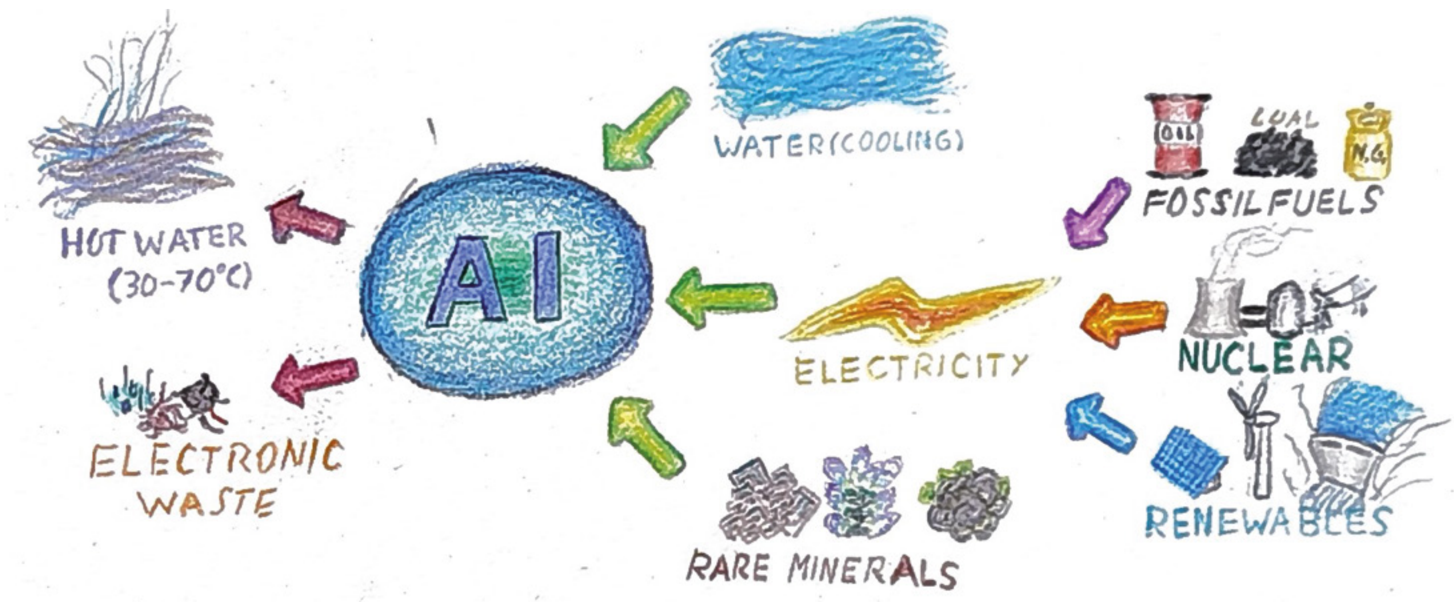
[1] https://unu.edu/inweh/news/environmental-cost-of-AIs-Enrgy-use-carbon-water-and-land-footprints

[2] https://doi.org/10.1016/j.patter.2025.101430

[3] https://www.eesi.org/articles/view/data-centers-and-water-consumption

[4] https://fieldreport.caes.uga.edu/wp-content/uploads/generated-pub-pdfs/TP-121.pdf

Inputs and Outputs of AI.



Career Updates

Aasim Jan is a new UTA PhD student and is moving from the LIGO group at UT Austin to Caltech LIGO Lab in the fall.

Debasmita Nandi received her PhD from Louisiana State University in August 2026 and moved as a postdoc to the Gravity Exploration Institute in Cardiff, UK. Her dissertation title was "Scattered light noise at LIGO Livingston Observatory induced by microseismic ground motion."

Gabriela González will start her position as president of the American Physical Association (APS) on January 1st, 2027. She was elected as APS Vice-President in 2024.

Karsten Danzmann becomes Director Emeritus: For more than three decades, Karsten Danzmann has been a leading figure in international gravitational-wave astronomy. The professor at the Institute for Gravitational Physics at Leibniz University Hannover and director at the Max Planck Institute for Gravitational Physics has played a central role in advancing major projects for gravitational-wave observation on Earth and in space. On 1 April 2026, he retired from the university and became Director Emeritus at the AEI.

Kielo Hoops (LIGO group at California State University Los Angeles) received his Master of Science degree in Physics with a thesis with the title "Characterization of optical scatterers in high reflectivity-coating materials for gravitational wave detection" on 8th August 2026.

Lucy Thomas is a Marie Curie Postdoctoral Fellow and is moving from Caltech LIGO Lab to the U Glasgow LIGO group at the end of August.

Mohit Raj Sah from Tata Institute of Fundamental Research, Mumbai, has defended his PhD thesis in July, 2026 on the topic 'Cosmology of Black Holes with MultiBand Gravitational Waves'.

Nick Johnson successfully defended his dissertation "Advances in Laser and Faraday Isolator Technology for Gravitational Wave Detectors" in July. His PhD was conferred in the August 2026 University of Florida summer graduation ceremony. He is now beginning a job as Assistant Professor at Alabama's Troy University.

Rafel Jaume has defended his PhD at the University of the Balearic Islands on continuous waves and detector characterization (supervisors: A.M. Sintes & S. Husa).

Rebekah Slocum graduated from Louisiana State University in May 2026 with a Bachelor of Science in Physics with a concentration in Astronomy from the College of Science, receiving the prestigious University Medal for graduating with the highest undergraduate grade-point average in the class. Her capstone thesis was "Investigating the Origins of Tomte Glitches in the LIGO Livingston Detector." She is now pursuing graduate school in the LIGO group at Syracuse University.

Simona Miller defended their PhD thesis at Caltech (advisor: Katerina Chatziioannou) and is going on to be CUNY's first ever Hubble fellow this fall.

Simona Miller is a new Caltech PhD student and is moving from Caltech LIGO Lab to Flatiron Institute and CUNY by the end of 2026.

Shreevathsa Chalathadka Subrahmanya moved from his postdoc position at University of Hamburg to a postdoc position at the Australian National University.

Storm Colloms has completed their PhD at the University of Glasgow and is moving to Pittsburgh to start as a McWilliams Fellow at Carnegie Mellon University.

Peter Saulson, emeritus professor at Syracuse University, was elected to the US National Academy of Sciences in 2026.

Yun-Jing Huang is a new Penn State PhD student and is moving from the LIGO group at Penn State to Caltech LIGO Lab in the fall.

Awards

Christophe Collette, professor at the Université de Liege, Belgium, obtained an ERC Proof-of-Concept grant for a giant high-resolution gyroscope project.

Elisa Maggio was recently awarded the Italian Fund for Science (FIS) Starting Grant Eyes-on-GR, whose goal is testing general relativity with multiband gravitational-wave observations. The grant is establishing a new research group in the Virgo collaboration at the Italian Institute for Nuclear Physics (INFN) in Rome, located at Sapienza University.

Graeme McGhee (University of Glasgow) won the European Astronomical Society's MERAC Prize for the Best Doctoral thesis in New Technologies. This prize includes 20k euro, 100k euro research funds and a plenary talk at the EAS annual meeting. His research is primarily in finding new optical coating materials for the test masses of GWDs that will lead to reduced thermal noise.

Jose Maria Ezquiaga (Niels Bohr Institute) was awarded the Lars Kann-Rasmussen Prize in 2026 https://the-center-of-gravity.com/news/jose-m-ezquiaga-awarded-lars-kann-rasmussen-prize-2026/

Jose Maria Ezquiaga (Niels Bohr Institute) was awarded an ERC StG which funds a 1.5M EUR project to search for lensed gravitational waves with LVK data. https://erc.europa.eu/apply-grant/starting-grant

Suvodip Mukherjee has been awarded the ICTP associateship in 2026.

New LSC positions

Edgard Bonilla was elected Chair of the Suspensions and Isolation Working Group.

John Veitch was elected to represent the Council on the LSC Management Team.

Ornella Piccinni was elected Co-Chair of the Continuous Waves group.

Patrick Sutton was re-appointed Chair of the Observational Science Division.

Rob Coyne was elected Chair of the LSC Council.

Volker Quetschke was re-appointed Chair of the Instrument Science Division.

Other News

Garret Cole and other LSC members contributed to an invited review article just published in Optica. The article was chosen to be the cover of the Issue with the image created by his daughter, Fiona Cole, himself, and Andri Gretarsson. https://opg.optica.org/optica/aboutthecover.cfm?volume=13&issue=8

Les Guthman's new LIGO documentary, "Squeezed Light: Breaking the Quantum Limit" won a Best Documentary award in April at the Physics on Film festival at the Institute of Physics in London. "Squeezed Light" will be released this fall. https://squeezedlightfilm.com

Vinzenz Aubry will become Artist-in-Residence at the Max Planck Institute for Gravitational Physics in the Potsdam Science Park and the Center of Gravity at the Niels Bohr Institute in Copenhagen. The Berlin-based artist will work on "Embodied Cinema: Vibrations for Androids III".

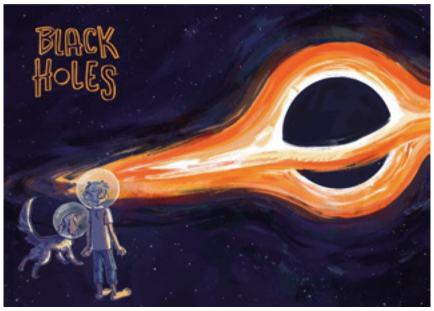
The first **Leibniz Science Campus** in Brandenburg, Germany, is being estab-lished in collaboration with the Max Planck Institute for Gravitational Physics: The campus titled "SCALES: Multiscale Challenges: from Astrophysics to Climate Models" is being set up in close collaboration with the University of Potsdam. It will be jointly funded for four years with a total budget of more than 4 million euros. **Tim Dietrich** (University of Potsdam and AEI) is serving as one of the two spokespersons.

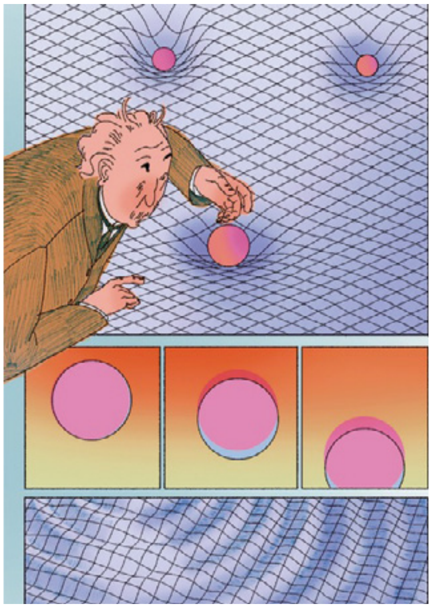
GWSky-Workshop: From 27 to 31 July, the workshop "Precision Gravitational Wave Astronomy: From Theory to Discovery" took place at the Sexten Center for Astrophysics, Riccardo Giacconi, Italy. This was the second annual workshop of the ERC Synergy GWSky project, which is led by Enrico Barausse, Zvi Bern, Alessandra Buonanno and Maarten van de Meent. The workshop brought together researchers working in theory, simulation and observation.

Researchers at the **Institute for Gravitational Physics at Leibniz University Hannover** and at the **Max Planck Institute for Gravitational Physics (Albert Einstein Institute)**, together with the **Laser Zentrum Hannover e.V.** and other partner institutions in Germany, have successfully secured funding for several projects as part of the Einstein Telescope preparatory program. Over the next three years, a total of approximately 4.3 million euros from the German Federal Ministry of Research, Technology, and Space is available for work at the institutes.

The **L**IGO **I**ndia - **V**acuum **I**ntegrated **S**ystem **T**est **A**ssembly **(LI-VISTA)** A facility is ready to take up intended experiments in coming days. LI-VISTA will serve as an experimental setup to take up specific experiments in UHV regime to study the performance of instrumentation in vacuum and cryogenics conditions and will aid LIGO-India project during Installation and commissioning phase.

Black Hole Comic Project: Physicists from the Center of Gravity at the Niels Bohr Institute (Copenhagen) partnered with six graphic storytelling students from The Animation Workshop / VIA University College (Viborg) to turn cutting-edge black hole physics into original comic stories. The comic premiered at The Center of Gravity's Black Hole Week Copenhagen 2026.
The project was made possible by a Carlsberg Mindelegat outreach grant, awarded to Rodrigo Panosso Macedo, in collaboration with Jose Maria Ezquiaga Bravo and writer Cecil Castellucci (www.cecilcastellucci.com). The complete comic is at https://blackholecomicbook.com.





LVK Mosaic from the 2026 Pisa Meeting

The LAAC got creative at the Pisa LVK Meeting, Spring 2026! Inspired by a similar public engagement project at the University of Glasgow (LIGO Magazine 9), attendees gathered to create a mosaic of the pixelated spectrogram of GW150914. For more details, and resources to use this yourself for any GW event, check out GWPaint at github.com/nnarenraju/gwpaint.

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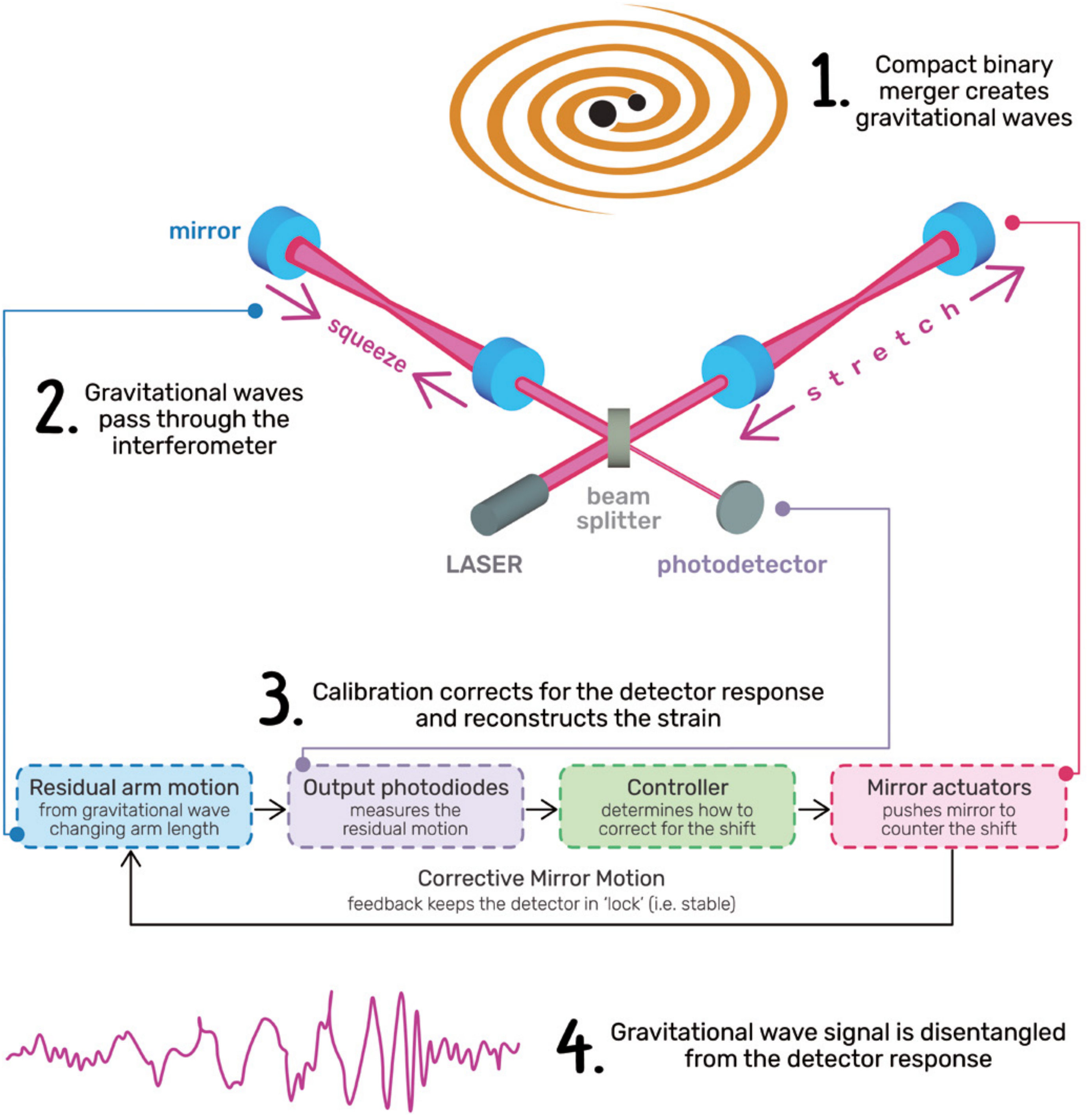
When disturbances and/or gravitational waves change the differential arm length, a feedback control system keeps the detector stable. The measured residual displacement is converted into a control force applied to the test masses, so the strain is not measured directly. Detector calibration reconstructs the strain from the detector raw output by accurately modeling and combining the detector's sensing and actuation responses.



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by Shanika Galaudage (graphic), Ling Sun (text)