LIGO Scientific Collaboration

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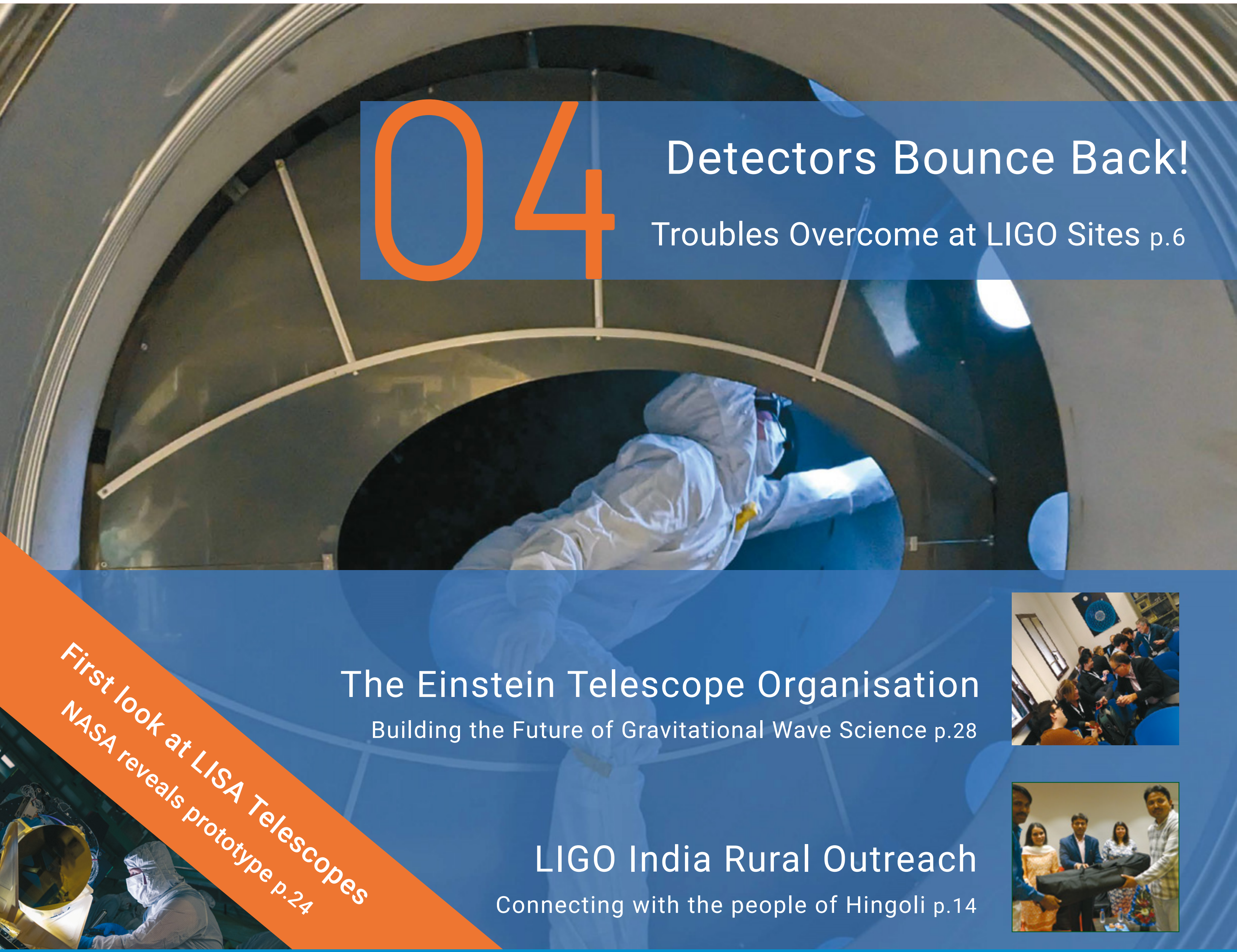
March/2025

LIGO MAGAZINE



Front cover

In "O4 Detectors Bounce Back" we hear about the repairs taking place at LIGO Hanford and LIGO Livingston. Part of the output Faraday isolator (OFI) repair procedure involved setting up a laser to use as an alignment reference in the chamber. Here, Sheila Dwyer climbs through a baffle to check the alignment of this temporary laser. Read the full story on pp.6-9.

Top inset: Lively discussions during a breakout session at Einstein Telescope Organisation's second general meeting. Rome, November 2024. Find out more about the Einstein Telescope Organisation on pp.28-29.

Bottom inset: LIGO India rural outreach. The photo shows the Collector (Anubhav Goel) and CEO (Neha Bhosale) of Hingoli distributing telescopes accompanied by Debarati Chatterjee. Read the full article on pp.14-15.

Bottom left (diagonal) inset: The LISA prototype telescope undergoes post-delivery inspection in a darkened NASA Goddard clean room on May 20. Image spread on pp.24-25.

Image credits

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Cover: Main image: O4 repair photo by Keita Kawabe. **Top inset:** ETO photo by Martine Oudenhoven.
Bottom inset: LIGO India outreach photo by Prasad Adekar **Bottom-left (diagonal):** LISA prototype telescope photo from NASA/Dennis Henry.
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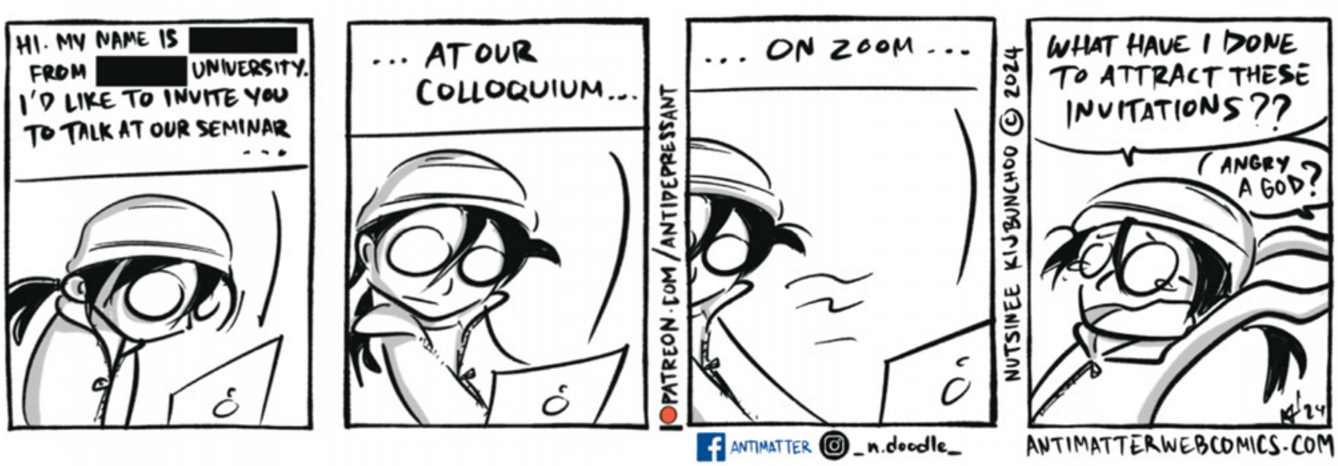
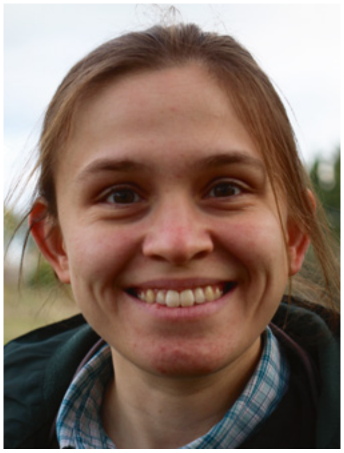


Welcome to the 26th issue of the LIGO Magazine!



Hannah Middleton
Editor-in-Chief

Anna Green
Deputy Editor-in-Chief

Welcome to the LIGO Magazine issue 26! It's not always smooth sailing with gravitational-wave detectors. The teams at LIGO Hanford and LIGO Livingston have been facing and overcoming challenges related to mechanical failures at each site. Sheila Dwyer and Karla Ramirez share their experiences from behind the scenes in "O4 Detectors bounce back!". Over at LIGO India, Saurabh Salunkhe has been connecting with the people of Hingoli, inspiring the next generation of scientists and countering misinformation by "Taking Gravitational Wave Science to the heart of Hingoli".

The gravitational-wave field is rapidly evolving with many challenges to face. Tackling them requires us to work together to foster a supportive, inclusive and welcoming environment especially in these uncertain times. In this edition, Mikhail Korobko & Sama Al-Shammari put a focus on building a strong community of early career scientists to help us face these challenges in "Empowering early career scientists to drive the next era of gravitational-wave science". We also catch up with Elise Sänger on the activities and objectives of LIGO-Virgo-KAGRA Climate & Sustainability Committee in this edition's Climate Change Conversation—see how you can get involved in this effort.

Taking a look back at the history of our field, we reflect on the life and struggles of Mileva Marić Einstein, the first wife of Albert Einstein. Their letters depict a couple united by a shared passion for physics and their collaborative works. Pauline Gagnon shares Mileva's story and the initiative to give her the recognition she deserves in "The forgotten life of Mileva Marić Einstein".

When describing gravitational waves, we often use the analogy of sound. In "What does the Universe sound like?", Christopher Taudt aka 'harte echtzeit' discusses how gravitational waves have inspired his music and creating techno tracks from chirps. We delve into the mysteries of black holes with Bartosz Fornal in "What happens when you fall into a black hole". And, after a decade working in gravitational-waves, we catch up with Chinmay Kalaghatgi on searching for systematics in banking in "Work After LIGO".

Finally, ever wondered what french fries have got to do with gravitational-wave detectors? Chiara Di Fronzo explains on the back cover.

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

Hannah Middleton and Anna Green, for the Editors

News from the spokespeople

We live in a time of considerable uncertainties. The success of our scientific endeavors depends on the worldwide collaboration that we have fostered and extended since the early days of LIGO. That collaboration enriches our research, scholarship and understanding. Therefore it's crucial that we maintain and extend a welcoming environment for talented individuals regardless of characteristics such as physical ability, race, ethnicity, gender, sexual orientation, economic status, national origin, or religious practices. We must work to remove the barriers that hinder full participation—building bridges over them, tunnels under them, and, when necessary, barging directly through them. It's going to be challenging, demanding creativity, patience, and unwavering commitment to our core values. Let's stay the course.

As of the end of February 2025, we've uncovered almost 200 significant gravitational-wave detection candidates in Observing Run 4 (O4). Alerts are distributed to astronomers and the public in less than 30 seconds. It's worth reflecting on the approximately 10,000 hours per week of LIGO Scientific Collaboration effort needed to do this day in and day out, month after month. That's equivalent to 285 people each working 35 hours per week. The work includes maintaining and operating the detectors, calibrating the data, characterizing the detectors and the data, operating a worldwide computing infrastructure, running gravitational-wave searches, supporting candidate annotation and alert generation, vetting candidates, and carrying out follow-up analysis. We are so grateful to every person that contributes to these essential science responsibilities on which we build our gravitational-wave searches and discoveries.

It's exciting to read the first of the Gravitational-Wave Transient Catalog (GWTC-4) papers that are in preparation. Observational results continue to drive improvement in our understanding of compact binary populations. The collaboration is fully utilizing gravitational-wave data to search for new sources and test general relativity, cosmology, and fundamental physics. There are currently 21 active O4 observational science papers covering compact binary observations, searches for unmodeled bursts, and searches for continuous gravitational waves. It's going to be a very busy six months getting these papers finished while continuing the rest of O4 data taking.

With the public releases of O4 data scheduled for August 2025 (for O4a), May 2026 (for O4b) and December 2026 (for O4c), we've got lots of exciting analysis to complete and write up by the end of next year. This will take a huge amount of work, so we encourage all Collaboration members to find ways to bring the Collaboration's observational science papers to completion as quickly as possible. These papers are the reward for contributing to the essential science responsibilities that allow us to collect and analyse the most sensitive gravitational-wave data.

As our leadership term draws to a close, it's gratifying to see the progress we've made as a collaboration. We are confident that the research, development and preparations for the upcoming detector improvements will pay major dividends in Observing Run 5, thus paving the way for even more observational science breakthroughs. It has been a privilege to serve as Spokesperson and Deputy. We believe that the future of our field depends on continued global collaboration and look forward to the implementation of the International Gravitational-Wave Observatory Network to better achieve our goals together.

Patrick Brady
LSC Spokesperson

Jess McIver
LSC Deputy Spokesperson

04 → Detectors bounce back! Site troubles overcome

We all know that detecting gravitational waves is hard. The technology required to achieve this remarkable feat is complex, and our instruments must be precisely tuned and controlled so they work harmoniously. While that complexity means that many things can go wrong, LIGO has needed few, if any, major repairs or emergency stoppages during the Advanced LIGO era. Unfortunately, our luck ran out in 2024, when both LIGO Hanford and LIGO Livingston observatories experienced serious mechanical failures that required immediate intervention; thankfully, not at the same time! Undeterred, staff at both facilities were able to make the needed repairs and get back to full operation without losing too much observing time. Below are the stories of how LIGO bounced back from adversity in 2024.

Sheila Dwyer is is a Senior Staff Scientist at LIGO Hanford Observatory.

Mystery Laser Damage Forces LIGO Hanford to Perform a Vent in Record Time

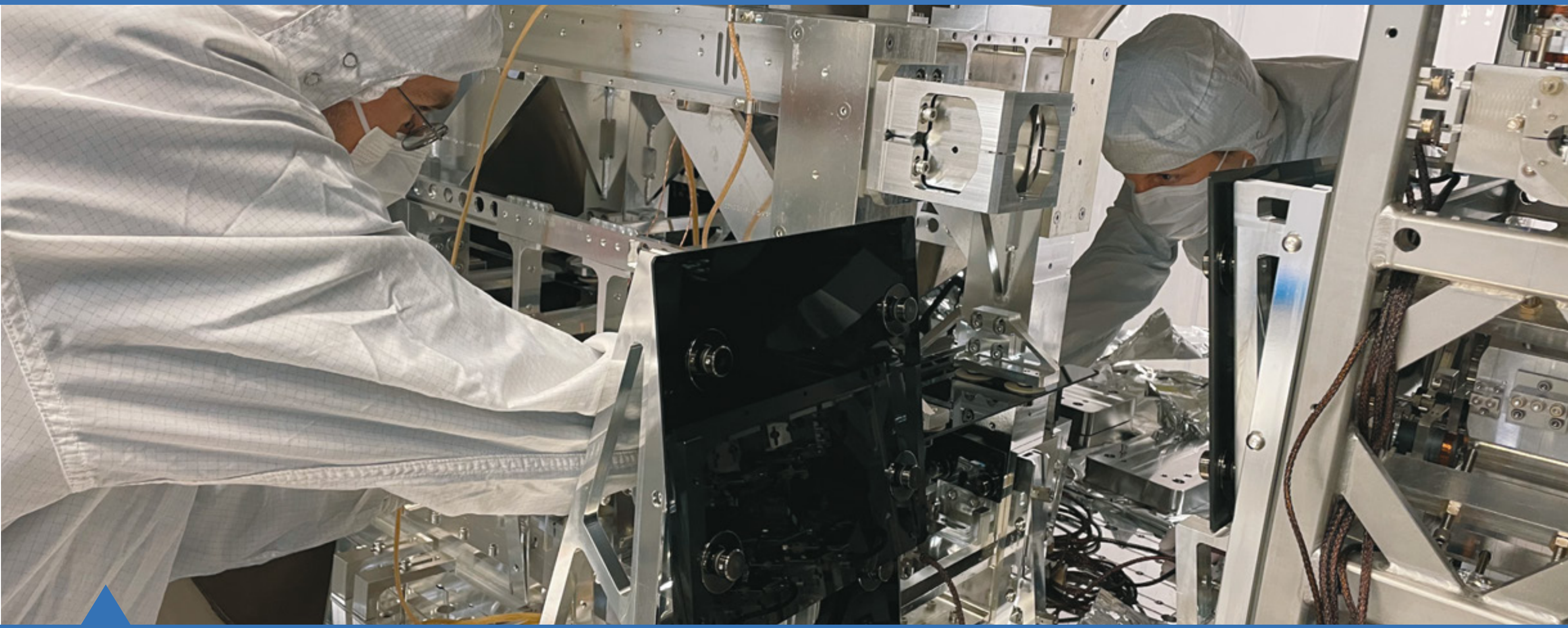
When the interferometer loses lock, a high energy pulse of light which has been stored in the arms can be sent toward the output chambers. A "fast shutter" in the interferometer output chamber is intended to protect sensitive optical components from being damaged by any such high energy pulses. The output Faraday isolator (OFI) is upstream of this fast shutter and is designed to handle these pulses without damage.

On April 22nd, 2024, LIGO Hanford Observatory (LHO) noticed 4% extra optical losses in the output arm of the interferometer. That loss caused additional energy to be deposited into some components during the lockloss energy pulse, which seemed to cause some damage, as the interferometer would not relock. The next day we deduced that some damage had likely occurred in the output Faraday isolator, (OFI) so the laser beam was shifted slightly to a different location on the OFI, allowing us to relock and restore the interferometer to sensitivity only slightly worse than before the damage. We continued observing, knowing that we likely had a damaged spot somewhere on the OFI, and efforts were made to ensure we had spare parts on hand in case of further damage.

Things were okay until July 12th, when there was a second similar incident. This time, it caused damage that we could not recover from and we realized we would have to perform an emergency vent. Normally, planning and preparing for a vacuum incursion could take a

First look at the damage to the KTP. Note the two laser-ablated pits in the optic, one from March and the second from July.

year or more. We didn't have that time, as we were in the middle of Observing Run 4 (O4), so this one was planned in just 6 days! On July 18th, we opened the chamber, and as soon as the door was removed, we saw that two craters had been blasted into the KTP crystal, used as a polarizer in the OFI (KTP by Sheila Dwyer & Karla Ramirez Guevara

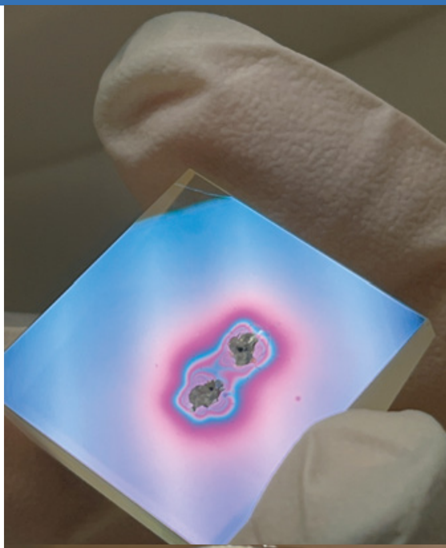


Jason Oberling (left) and Camilla Compton (right) carefully remove the KTP.

refers to the chemical makeup of the optic: potassium titanyl phosphate). In discussion with the OFI design team from University of Florida and Montclair State, we decided that we would try to replace the damaged parts in the chamber.

Sometimes seemingly simple things can be difficult during in-chamber work. For example, removing the bolts that hold a beam dump on the KTP mount. The Faraday rotator is just a few inches from these bolts and is housed in a strong magnet, so someone using a steel allen key could easily slip and the tool could fly off and strike the magnet, potentially damaging optics or the magnet itself. We have titanium allen keys cleaned for in-vacuum work around these strong magnets, but none of them could fit into the tight space available. The search for a non-magnetic tool, which could be purchased, modified, and cleaned quickly involved at least 5 people! Another challenge was that the output Faraday isolator is also on a suspended platform, which could only be partially locked down for the KTP removal - a tense moment.

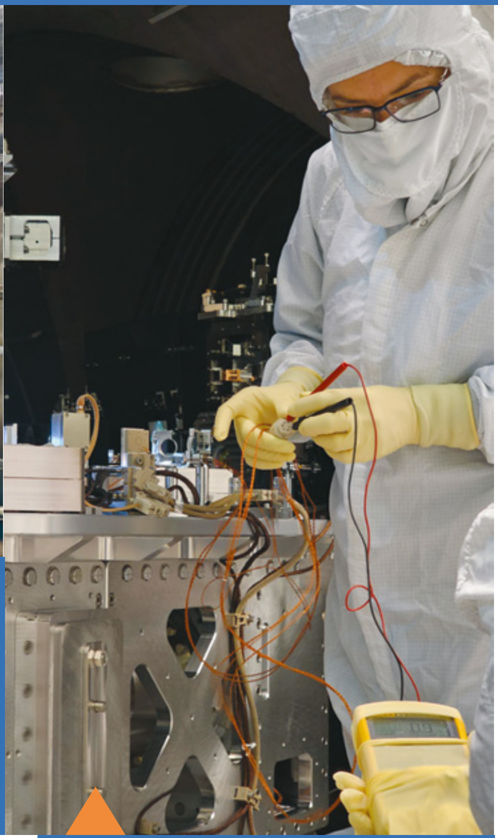
Unfortunately, while placing a spare KTP in the mount, we chipped it. After studying how it was chipped we realized we couldn't use it, so we placed our last spare crystal in the mount. Aligning the KTP in the Faraday isolator in-chamber went smoothly, but we realized we also had to replace the fused silica wedge, which had been spattered with material from the KTP. We made some measurements of the Faraday's transmission and isolation, or how well it prevents light from HAM6 from returning to the interferometer.



Top: *This image, taken after the KTP was removed, shows the damage caused by the laser. The two 'craters' dated from April and July. Refraction of visible light through the infrared anti-reflective coating on the crystal makes the full extent of the damage more visible.*

Bottom: *Laser-ablated spatter from the KTP landed on the fused silica wedge which was situated across from the KTP. The wedge is an optical device that directs the laser through the Faraday Isolator into the KTP.*

Anamaria Effler and Adam Mullavey inspecting surrounding components for damage caused by the Fast Shutter failure—thankfully, they found no signs of damage!



Anamaria performing a continuity test on the in-vacuum cables for the Fast Shutter in HAM6, searching for shorts before we discovered that the issue was with the Fast Shutter itself.

Once the in-chamber work was complete, the vacuum team began the process of installing doors and pumping down the corner station vacuum. Pumpdown began on August 6th, and the gate valves were opened on August 21st, making this the fastest corner station pump-down we've ever performed.

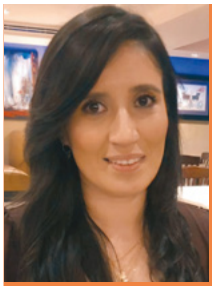
Since the repair, LHO has continued O4 observations without further issues. The root cause of the damage (i.e. why the laser went astray) is still under investigation.

– Sheila Dwyer –

The Fast Shutter Enigma: A Story of Determination and Creativity at LIGO Livingston Observatory (LLO)

Deep within the intricate network of the interferometer, immense power, nearly 300 kW, circulates through each arm. When the IFO loses lock, this energy must find a way to dissipate. This energy is reflected back toward the beam splitter, which, like an impartial judge, divides it between the reflection (REFL) and anti-symmetric (AS) ports. On average, 15 J travels to the AS port, strong enough to overwhelm its sensitive detectors.

Here is where a "Fast Shutter" enters into action, a quick and vigilant protector. The moment the trigger photodetector senses a lock loss, it signals the Fast Shutter to snap into action, rapidly blocking the power transient before it can do any damage. In this brief yet critical instant,



Karla Ramirez is a Detector Engineer at the LIGO Livingston Observatory, currently working on VMD and HXDS suspension assemblies. This year, she celebrates her fourth anniversary with LIGO. When she's not working, she enjoys spending time with her husband, David, and their daughter, Lucy—not to mention her six beloved cats!

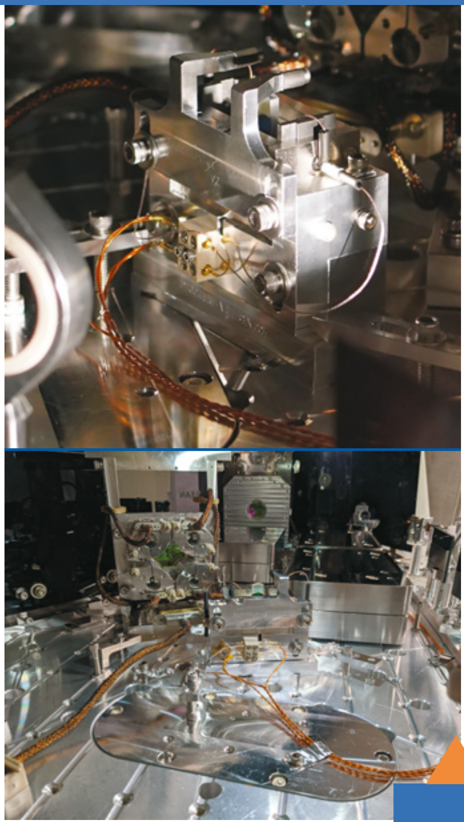
the Fast Shutter stands as a line of defense, shielding the AS port detectors and the Output Mode Cleaner (OMC) from destructive bursts of energy, ensuring the system remains protected and ready for the next cycle of precision measurement.

It began like any good mystery at LIGO Livingston Observatory (LLO), with a clue that pointed to trouble. It was a seemingly normal night on October 10, 2024, when the interferometer (IFO) unexpectedly lost its lock and remained down. The culprit? A glaring message: FAST SHUTTER FAIL.

As the Detector Engineer on call that week, I received a call letting me know the IFO needed my assistance. While I'm not yet an expert in this area, I quickly called Joe Betzwieser for help. He found that the Fast Shutter (FS) had failed to trigger when it should have. To address the issue, he made some changes to the code to ensure the FS would function as expected.

However, the next day brought no relief. The IFO remained down, and it became clear that we had a bigger problem on our hands. Thus, the hunt to uncover the cause of the FS malfunction began.

The team eventually identified an electrical short between the FS and HAM6 chamber, but the exact location of the short remained a mystery. Determined to solve the problem, we decided to vent HAM6 and investigate more closely.



Top: *Detector Down: Fast Shutter Fail.*

Bottom: *Fast Shutter ready for the next lockloss.*

Once HAM6 was opened, our attention turned to the FS assembly, D1003318-v4 SN 005, sitting innocently on the table.
At first glance, it appeared fine, but experience told us otherwise. With careful inspection, we found the culprit: a wire with damaged insulation. The kinked wire was unmistakable, a small defect that caused a significant issue.

Armed with this knowledge, we replaced the faulty FS assembly with a spare unit, D1003318 SN 002, from LIGO Hanford Observatory (LHO). After installing it, we ran a series of tests. The 'slow up' and 'slow down' commands worked perfectly, and hope began to build. But during the 'fast up' test, disaster struck again - the tombstone part of the FS bobbin-coil assembly, where the optic is glued to the coil, broke apart.

With no additional FS assemblies available at either site, the situation looked grim. Just as hope seemed to be slipping away, a lifeline arrived: a spare bobbin-coil assembly, D1003319-v4, from the 3rd IFO at LHO.

The next step required a combination of technical expertise and ingenuity. We installed the spare bobbin-coil assembly into the original FS assembly, D1003318 SN 005, and made modifications to the fast shutter cap. The modifications were made to prevent the wire from being struck during operation and to minimize the risk of future damage.

Finally, the moment of truth arrived. With the system reassembled, we tested the FS—and it performed flawlessly. Every command was executed with precision. What began as a FAST SHUTTER FAIL warning transformed into a story of teamwork, creativity, and resilience.

For those curious about the technical details, you can find more information in alog LLO73595.

And so, we've overcome yet another challenge at LLO! This truly shows how amazing things can happen when determination and creativity come together.

– Karla Ramirez Guevara –

The forgotten life of Mileva Marić Einstein

Mileva and Albert Einstein in 1912

My work on Mileva Marić Einstein

Nearly 35 years ago, I came across a very short article about Mileva Marić Einstein in a feminist magazine. I was quite intrigued but failed to find any more information about her for more than a decade in those pre-internet days. At the time, the only existing biography on her was written in Serbian, with a translation into German.

But then, in 2010, as I was shift leader in the ATLAS Control Room, I ran into Judita Mamuzić, a graduate student from Serbia. I asked her if she had ever heard of Mileva

Pauline Gagnon

(Retired Senior Research Scientist, Indiana University) has been researching the life of Mileva Marić Einstein for about 15 years now and has been active ever since giving talks about her. Pauline enjoys walking, biking and working on a mini series dedicated to Mileva Marić and other female scientists.

Marić. "Of course!", she immediately replied. "She is a national hero in Serbia." How could that be when she is totally unknown in the rest of the world? Judita and I decided to search the CERN Library and discovered many books on her, most importantly a thorough biography written by Radmila Milentijević which appeared in French in 2011 (my mother tongue), then in English in 2013.

What we discovered was in such contrast with the story we had heard about Albert Einstein, the lone genius, that I decided to include an appendix on Mileva Marić in my popular science book on particle physics, which I published in 2015. I gave my first public presentation at Université Laval in Quebec City in 2015 and have since given 50 talks as physics colloquia, in conferences or to general audiences in 14 countries spanning four continents. I must admit, I was quite nervous at the beginning, not knowing how the audiences, especially physicists, would react. I expected violent opposition but on the contrary, my talk has always been very well received, even at ETH Zurich where I gave a physics colloquium talk in 2021. I recently gave it as an invited talk in front of 3000 people at NWO, the largest physics conference in the Netherlands but again, the support I received was amazing. Once, at University of Maryland, Ted Einstein, a retired physics professor and an expert on his distant cousin, grilled me thoroughly for hours before and after the colloquium talk. In the end, he too had to admit that I had presented a pretty strong case.

Clearly, the times have changed and given the evidence, people are willing to change their opinion and look at the collaborative work of Mileva Marić and Albert Einstein in a different light. I hope my efforts will contribute to seeing Mileva Marić given the credit she deserved, starting with a posthumous degree from ETH.

The Forgotten Life of Mileva Marić Einstein

Albert Einstein is often celebrated as the best physicist of the century, but how much did his first wife, Mileva Marić, contribute to his groundbreaking science? While it is not possible to credit her with any specific part of his work, their letters and numerous surviving testimonies show how they collaborated for two decades. These letters depict a couple united by a shared passion for physics, music and for each other. Here is her story.

Mileva Marić was born in 1875 in Titel, now part of Serbia. Her father recognized her talent and supported her studies, even though girls were prohibited from studying under the Austro-Hungarian rules. She went to Zurich to complete high school in 1894, where her classmates described her as brilliant but reserved, perseverant and thorough.

Albert Einstein, born in Ulm, Germany in 1879, was inquisitive but bohemian and rebellious. He hated the discipline of German schools, so he finished high school in Switzerland.

Albert and Mileva entered the physics-mathematics section of the Polytechnic Institute in Zurich (now ETH) in 1896 with three other students. They became inseparable, spending countless hours studying together instead of attending lectures. Mileva was methodical and organized. She helped Albert focus as we learn from his letters: 43 letters from Albert to Mileva survived but only 10 of hers remain. These letters provide a first-hand account on how they interacted at the time. For example, on 28 September 1899, Albert wrote: "I am beginning to feel the absence of your beneficent thumb, under which I am always kept in line." [1]

Mileva lived with her life-long friends Helene Kaufler-Savić and Milana Bota. Both spoke of Albert's continuous presence at Mileva's place. Milan Popović, Helene's grandson, published the letters Mileva exchanged with Helene throughout her life [2].

By the end of their classes in 1900, Mileva and Albert had similar averages: she, 4.7 and him, 4.6 out of 5. But at the oral exam, Prof. Minkowski gave the four male students 11 out of 12 and only 5 to Mileva. Only the four men got their degree. Mileva was the fifth woman admitted to the physics-mathematics section and the first in physics. None of the previous women received their degree.

> *"I am beginning to feel the absence of your beneficent thumb, under which I am always kept in line."*

Meanwhile, Albert's family strongly opposed their relationship. His mother said: "No decent family will have her", as Albert reported to Mileva in a letter dated 27 July 1900. Mileva was neither Jewish nor German but Serbian, with all the prejudices against Slavic people.

Upon graduation, all students received assistant professor positions except Albert. He suspected that professor Weber, whom he had repeatedly insulted, was blocking him. Without a job, Albert refused to marry Mileva.

On 13 December 1900, Albert submitted his first article on capillarity to the Annalen der Physik, signed under his sole name. However, both referred to this article in different letters as being common work. Why? Radmila Milentijević, author of Mileva's most comprehensive biography [3], suggests that Mileva probably wanted to help Albert make a name for himself, and find a job, enabling him to marry her. Moreover, Milentijević argues that Mileva, having been raised in a very patriarchal family, saw it as her duty to support her husband at all cost.

Dord Krstić, a computer science professor at Ljubljana University, spent 50 years researching Mileva's life. In his well-documented book [4], he suggests that given the prevalent biases against women at the time, a paper co-signed with a woman might have carried less weight. But foremost, having been denied a degree, she had no legitimacy to sign a paper.

In addition, for Mileva, they were one unique entity–as she later said to their friend Conrad Habicht, who questioned Mileva's choice not to include her name on a patent for a device the three of them had designed. She simply said: "Warum? Wir beide sind nur ein Stein". ("Why? The two of us are just one stone", meaning, we are one).

We will never know. But nobody made it clearer than Albert Einstein himself that they had collaborated on special relativity when he wrote to Mileva on 27 March 1901: "How happy and proud I'll be when the two of us together will have brought our work on relative motion to a successful conclusion."

Albert, still unemployed, refused to marry her even when she got pregnant in the spring of 1901. In July, Prof. Weber, who loathed Albert, failed Mileva on her second and final attempt at the oral exam. Forced to abandon her studies, she returned to Serbia but came back twice, unsuccessfully trying to persuade Albert to marry her. She gave birth to a girl named Lieserl in January 1902. No one knows what happened to her.

Even though Albert heard as early as December 1901 of a post for him at the Patent Office in Bern, he only married Mileva on 6 January 1903. Meanwhile, the loss of her daughter drove Mileva into chronic depression.

"How happy and proud I'll be when the two of us together will have brought our work on relative motion to a successful conclusion."

At the Patent Office, Albert worked 8 hours a day, 6 days a week while Mileva assumed the domestic tasks. In the evenings, they worked together, sometimes late in the night. On 14 May 1904, their son Hans Albert was born.

Mileva's brother, Miloš Jr, a student of medicine, stayed with the Einstein family while studying in Bern. Krstić wrote: "[Miloš] described how in the evenings and at night, when silence fell upon the town, the young married couple would sit together at the table and by the light of a kerosene lantern, they would work together on physics problems. Miloš Jr. spoke of how they calculated, wrote, read and debated."

In 1905, came the "miracle year", when Albert published five astonishing papers on the photoelectric effect (1921 Nobel Prize), Brownian motion, special relativity and $E = mc^2$. He also submitted his thesis on the dimensions of molecules. Much later, Albert told R. S. Shanklank [5] that relativity had been his life for seven years and the photoelectric effect, for five years. Peter Michelmore, another of his biographers [6], wrote that after having spent five weeks to complete the article containing the basis of special relativity, Albert went to bed for two weeks. Mileva checked the article again and again, before mailing it. Exhausted, the couple took a first vacation in Serbia where they met numerous people.

Mileva told her father: "Before our departure, we finished an important scientific work which will make my husband known around the world."[7] Krstić heard this in 1961 from Mileva's cousin, Sofija Galić Golubović, who was present when Mileva spoke to her father. Krstić heard the same testimony from two other relatives of Mileva, who had heard it from her father.

Zarko Marić, Mileva's father's cousin, told Krstić how the couple often sat in the garden to discuss physics, calculating and debating. Harmony and mutual respect prevailed.

Mileva's brother often hosted gatherings of young intellectuals. During one of these evenings, Albert declared: "I need my wife. She solves for me all my mathematical problems",[8] as reported by Živko Marković, mayor of Novi Sad.

Recognition first came in 1908 with an unpaid lecturer position in Bern followed by a position in Zurich in 1909. Mileva was still assisting Albert. Eight pages of his first lecture notes are in her handwriting. So is a letter drafted in 1910 in reply to Max Planck, who had sought Albert's opinion.

Their second son, Eduard, was born on 28 July 1910. But in 1912, Albert started an affair with his cousin, Elsa Löwenthal. They maintained a secret correspondence over two years until Albert accepted a faculty position in Berlin in 1914 to be closer to Elsa.

This affair caused their marriage to collapse. Mileva returned to Zurich with her sons on 29 July 1914. She agreed to divorce in 1919, with a clause stating that if Albert ever received the Nobel Prize, she would get the money.

Her son Eduard frequently had to stay in a sanatorium. He later developed schizophrenia and was eventually internalised. Due to these medical expenses, Mileva struggled financially especially at the end of her life. She survived giving private lessons and on the alimony Albert sent, albeit irregularly.

In 1925, Albert wrote in his will that the Nobel Prize money was to be considered his sons' inheritance. Mileva strongly objected, stating this money was hers as stipulated in the divorce agreement. She must have considered revealing her scientific contributions since Albert replied with a harsh letter dated 24 October 1925 (AEA 75-364). "But you really gave me a good laugh when you started threatening me with your memories. Doesn't it ever dawn upon you for even a single second that no one would pay the least attention at all to your rubbish if the man with whom you are dealing had not perchance accomplished something important? When a person is a nonentity, there's nothing more to be said, but one should be modest and shut up. I advise you to do so."[9]

Mileva never spoke publicly but confided in some close people, like her friend Milana Bota, who reported it to the Serbian newspaper Vreme in 1929; her student Maja Shucan, who repeated it to Einstein's biographer Highfield; and her godparents, mother, sister and older son, according to Krstić.

Hans Albert and his first wife, Frieda, tried to publish the letters his parents had exchanged in their youth but were blocked in court by the Einstein's Estate Executors, Helen Dukas and Otto Nathan in 1958, in an attempt to preserve the Einstein's myth. The letters were only released in 1987 after Nathan and Dukas' deaths.

Albert and Mileva's union was based on love and mutual respect, which allowed them, together, to produce outstanding work. She was the first person to recognize his talent. Without her support, he would never have succeeded and would have remained a failed academic at the Patent Office. She sacrificed her own aspirations, happy to work with him and contribute to his success, feeling they were "ein Stein". Once started, the subterfuge of signing their work under his single name became impossible to reverse, having agreed to it since her own happiness depended on his success. And as is always the case in close collaborations, the individual contributions are nearly impossible to disentangle.

Even if Albert Einstein had acted differently, Mileva's brillant destiny vanished when she was unjustly denied her degree. For this reason, please join the initiative started by Gabriella Greyson. You too can write to the Rector at ETH Zurich to request they grant Mileva Marić, and the other women who were failed before her, a posthumous degree.

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Left: *Explaining space-time continuum to school kids.*
Right: *Gauri Padalkar explaining LIGO to teachers.*

Taking Gravitational Wave Science to the heart of Hingoli

Saurabh Salunkhe

A dreamer by day and a stargazer by night, I find my inspiration in the cosmos. Formerly an Assistant Professor of Physics, I am now dedicated to astronomy education and public engagement, currently serving as a Senior Outreach Coordinator for the LIGO-India project at IUCAA, Pune.

Setting foot on Hingoli railway station's platform number 2 at noon felt like stepping into another universe! Coming from the fast-paced streets of Mumbai, this rural setting was a whole new adventure for me. But hey! I was there on a mission. A mission to connect with the amazing people of Hingoli and bring the magic of LIGO-India for them.

Before I brief you about our mission and protocols that we followed to get this accomplished, let me give an overview of Hingoli. Hingoli, a district in Maharashtra, is part of the Marathwada region. It's hot, arid, and prone to droughts. Summers can be brutal, with temperatures soaring to 41°C but the people you ask? Warm and welcoming. They speak Marathi, just like me, but with a unique twist to their dialect. Oh, and the food? Spicy and full of flavor, just the kind of kick you need to keep going!

To avoid getting roasted by the summer sun, I started the outreach programme in January 2024, when the weather was much cooler and way more forgiving. My train from Pune was fashionably late by five hours. But hey! Come on, we are on an adventurous mission, things are never going to work as we want.

Let's start, now that we have defeated the sun, we need to counter the misinformation. For that, we need to understand the misinformation and the source of it. So, for that we need to connect to the locals. As Sir Isaac Newton once said, "If I have seen further, it is by standing on the shoulders of giants." I leaned on the fantastic work done by previous LI-EPO coordinators and IUCAA Sci-Pop to connect with key local figures such as the District Collectors, Education Officers, and Vice Chancellors of regional universities. With their help, I was ready to dive into the real work.

Let's sharpen our swords with information so that we can tackle its enemy. LIGO-India is the third LIGO detector in the world and the sixth gravitational wave detector ever! It's being built in Hingoli's Aundha-Nagnath area by India's Department of Atomic Energy (DAE) and the Department of Science and Technology (DST), in collaboration with the National Science Foundation (NSF) from the USA. The project is being led by four Indian institutions: Inter University Centre for Astronomy and Astrophysics (IUCAA) in Pune, Raja Ramanna Centre for Advanced Technology (RRCAT) in Indore, Institute for Plasma Research (IPR) in Gandhinagar, and Directorate of Construction Services and Estate Management (DCSEM) in Mumbai.

As we dwelt deeper into Hingoli outreach, in our multiple frequent visits not always in the pleasant weather of January, we got to know the rumors and misinformation that were swirling around within the misinformed locals, and others by not-so-helpful media outlets. Now to combat that, we organised two teachers' training workshops. Now this was a bit difficult to handle as a 24 year old, it became difficult to convince teachers older than me that we are going to train them, but we managed it as we had backing from Hingoli's key people. Honestly, during the first workshop, I was all nervous and sweating. Hosting and training well experienced teachers all from conservative backgrounds is no joke in India. The idea was simple: equip teachers with the correct information about LIGO-India and gravitational waves, so they can pass it on to their students. We even gave them a handy LIGO-India Science Guide Book in both English and Marathi.

No mission is complete without inspiring and interacting with the youth of the region. For this we, organised multiple local school and college outreach events. To support the young, intelligent and enthusiastic about science generation of students in the region, we had organised a basic Python workshop in July and August of 2024 and are actively working towards providing them intermediate and advanced Python workshops sooner.

For our further missions to Hingoli, we will be tackling the low participation of women in STEM.

Kids, you ask? Well stupendous amount of energy, enthusiasm, and never ending imaginary astronomical questions. We discussed the basics of science and astronomy along with how LIGO-India is a BIG astronomy project. This also helped in demystifying the project among the children and their families. By the end of our sessions, the kids were cheering, "LIGO-India!" It was the ultimate mic drop moment. I wish we could add videos and audios like Harry Potter in a printed magazine.

To keep the astronomy vibes alive, we organised two Starfest events in 2022 and 2025 in which we had lectures and discussions on Physics, Telescopes, Astrophysics, GW and LIGO. We distributed popup books titled "Listening to the universe" in Marathi along with five 5-inch newtonian telescopes and ten 2.5-inch refractor telescopes which we had received from a generous donation of Newton-Bhabha funds. We have also created five amateur astronomy clubs or *Khagol Manch* in Hingoli, one for each taluka (sub district) which are supported by LIGO-India EPO. Because who wouldn't want to stargaze under Hingoli's vast beautiful skies with minimum light and air pollution?

The battle against misinformation has nearly been won but success was not fully accomplished. For our further missions to Hingoli, we will be tackling the low women participation in STEM which is very prevalent in India, and Hingoli is no exception in it. We wish ourselves the best of luck!

***Top:** GW dance after a successful workshop.. **Bottom:** Debarati Chatterjee and Anubhav Goel presenting "Listening to the universe", Marathi Book.*

Climate & Sustainability Committee

View from Mount Wilson Observatory of the wildfires around Los Angeles earlier this year. Several LIGO members lost their homes due to the fires, and many more were evacuated. Caltech and JPL have set up a Disaster Relief Fund to support their affected staff and students. Please consider making a contribution at https://giving.caltech.edu/areas-to-support/relief.

It is my great pleasure to announce the formation of the LIGO-Virgo-KAGRA (LVK) Climate & Sustainability Committee. We began in 2019 as an ad-hoc committee with discussions on reducing the LIGO Scientific Collaboration's (LSC) climate impact. This group has now been officially recognized as a standing committee within the LSC, Virgo, and KAGRA. All LVK members are welcome to attend meetings of the Committee and help us explore ways to lower our climate impact.

The mission of the Climate & Sustainability Committee is to facilitate the LVK collaborations and their members to take action on climate change and sustainability. The goals of the Committee are twofold:

(i) Evaluate and reduce the climate impact of the LVK and its activities;
(ii) Raise awareness, both among LVK members and the outside community, about climate change and actions that we can all take to mitigate climate change.

Elise Sänger

is a PhD student working on testing general relativity at the Max Planck Institute for Gravitational Physics (AEI) in Potsdam, Germany. In her free time, she enjoys reading and playing games, both the physical and digital kind.

Throughout this article you will find quotes from members of the Committee on their motivation for joining the climate and sustainability efforts of the LVK. We hope these will serve as inspiration.

Why should we care?

There is strong scientific evidence that climate change is happening, and that human activity is responsible for it. The increase in global temperature leads to severe weather patterns with floods, droughts, hurricanes, blizzards, wildfires, etc. becoming more common and more intense. These all have devastating effects and climate change is or will be directly or indirectly affecting all of us.

"We are at a crossroads with regards to climate change; the world has not yet taken decisive action and the window to do so is quickly shrinking. We have the privilege to be scientists and it is our duty to be at the forefront of the fight against climate change both within scientific spaces and outside" – Sharan Banagiri, Monash University, Melbourne

But why should we as scientists and as a collaboration engage in the effort to limit climate change? Firstly, climate change will impact all of us in one form or the other, if it hasn't already done so. And as fellow scientists, it is our responsibility to follow and support the ethical and policy considerations borne out of climate science.

"The scientific community can and should set an example of best practices to reduce our environmental impact and this is also an opportunity to reflect on the way we work and on the impact of science on society." – Matteo Barsuglia, APC/CNRS, Paris

Solving the climate crisis will require both a global cooperative effort to minimize CO_2 output, and technological innovation to develop and deploy sustainable energy solutions. Our collaboration has both the social awareness and the brain power to make a positive contribution on both of these fronts.

In addition, climate change is affecting us as a community. We need look no further than the tragic wildfires around Los Angeles (USA) this year. Wildfires in January are unprecedented in Los Angeles, and their occurrence has been strongly linked

"Science is part of society and we need to be aware of our impact, negative as well as positive. As an international collaboration we likely contribute disproportionately to the CO_2 crisis. We thus should find out what our negative impact is, be aware of that and find measures to reduce it." – Gijs Nelemans, Radboud University, Netherlands

to changing weather patterns due to climate change. Several LIGO members lost their homes due to the fires, and many more were evacuated. The fires also impacted the LIGO computing infrastructure at Caltech causing several systems to go offline. As another example, just a few months ago, extreme rainfall in Europe led to devastating flooding across Valencia (Spain). These are sadly just two recent examples of extreme weather events affecting the livelihoods and science of scientists, at an increasing frequency.

Severe weather can also limit our ability to do science by degrading the performance and uptime of our gravitational wave detectors. Besides this direct impact on our science, there is also the impact of people being personally affected by severe weather and therefore not being able to work.

Carrying out our activities as a collaboration, we generate greenhouse gasses and thus contribute to climate change. It is therefore our responsibility to reduce our carbon footprint and work towards being climate neutral. We cannot expect others to do this for us. We should do our part in limiting climate change. While our scientific research has worth in and of itself, as responsible citizens and scientists,

"Science is ever more vital in addressing the challenges of our age. At this critical time, there is a developing distrust of scientific knowledge and expertise. As scientists, we have a responsibility to educate ourselves about climate change, which poses a profound long-term threat to civilization as we know it. As scientists, we also have a role to inform and engage with the public, helping to convey the immense beauty and power of the scientific enterprise." – Daniel Holz, University of Chicago, USA

it is our duty to limit and mitigate any negative impacts of it. This is the main impetus behind the Climate & Sustainability Committee.

What can we do?

A rough estimate of the total carbon footprint of the LVK gives about 10 kt CO_2 per year. To put this into perspective: this is about 5 additional tonnes CO_2 per LVK member per year, which is comparable to the world average per capita CO_2 emission of 4.7 tonnes per year [1]. To learn more about the LVK's carbon footprint, check out the climate conversations article in the March 2023 edition of the LIGO Magazine [2].

"Actors from different research and practice communities must engage to provide a framework for understanding climate change and its impacts and to support the implementation of solutions that reduce or avoid climate risk and associated loss and damages (both economic and non-economic). As researchers and practitioners, we have a duty to do our best to reduce adverse consequences of climate change for current and future generations." – Francesca Spagnuolo, European Gravitational Observatory/VIRGO, Italy

So what could we do to reduce the LVK carbon footprint? Some obvious high impact things include switching

"Climate change is happening and is negatively impacting our world. We should take our responsibility and do our part in limiting climate change by reducing our climate impact as much as possible." – Elise Sänger, Max Planck Institute for Gravitational Physics (AEI), Potsdam, Germany

to renewable power for detector sites and computing clusters (for those not already using renewable energy). But this is not always as simple as it sounds since we are dependent on what energy sources and power suppliers are available. We could also look into installing solar panels at the detector sites, which raises questions about any impact on the detectors. Other things that could be done are reducing the amount of travel to meetings by making some of them virtual, increasing the efficiency of computing algorithms, and reducing redundancy in our computing. Part of the objective of the Committee is to investigate what material improvements are feasible and how they might be funded.

"With the blast of the global temperatures beyond the 1.5°C target in 2024 and the disastrous weather consequences that followed, it is impossible to do nothing about our home planet. We, scientists, all possess the skills and dedication to make breakthrough discoveries, so I believe we must solve the climate crisis, too. LVK's work, as anyone else's, does not come free of emissions by default. We must understand our climate impact and push as much as possible to drive our emissions to a perfect, solid round zero." – Ivan Markin, University of Potsdam, Germany

Besides reducing the climate impact of the LVK, it is also important that we take advantage of our capabilities as teachers and communicators to educate LVK members as well as the outside community about climate change. We should talk about what we do to reduce our emissions, as well as teach people how they can reduce their climate impact. We should also use our experience to inform future detector builders about what should and should not be done, so that so that detectors can be built with sustainability in mind.

Want to join?

The Climate & Sustainability Committee meetings are open to everyone in the LVK who is interested. Please join one of the monthly telecons if you would like to learn more about or discuss climate and sustainability-related issues. Also do not hesitate to contact us if you have any questions, would like to help with a project, or have an idea for something that the Committee can do. LVK members can sign up for our mailing list [3] or join our Mattermost channel [4].

LIGO 2025

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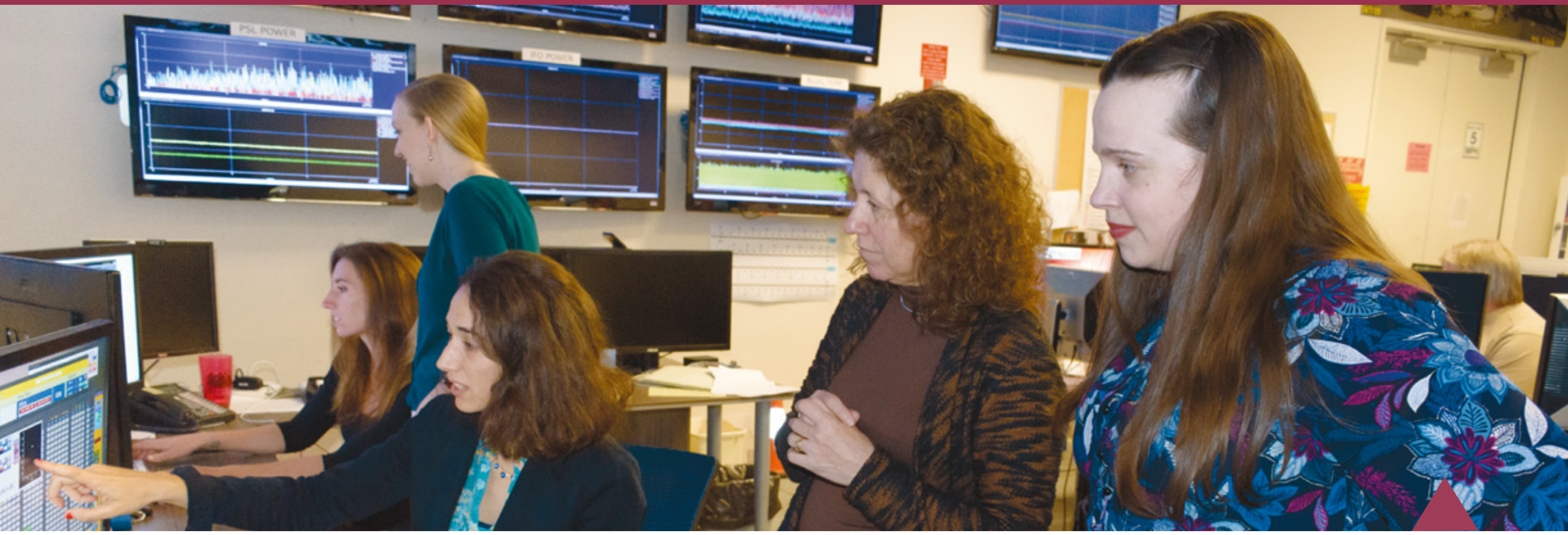
Remembering Amber Stuver



Amber Stuver (right) and Gaby Gonzalez look on as Marie Kazprzack, Marissa Walker, and Terra Hardwick work in LIGO Livingston's control room.

Amber Stuver, a dear LIGO colleague, tragically passed away on September 8, 2024, from a blood clot in her lung. Amber grew up in Greensburg, Pennsylvania. She was a graduate of Penn State University, where she earned a master's degree in education co-advised by Gabriela González, followed by a PhD in 2006 with Sam Finn as her advisor. Her research focused on how to search for unmodelled bursts, work she continued throughout her career. She joined Caltech and the LIGO Livingston Observatory as a postdoc in 2007, working on burst data analysis and also showing strong dedication to the then-new LIGO Science Education Center program. After her postdoc ended, she split her time between Caltech/LLO science duties and instruction at LSU. Her husband, Derek Bridges, also worked at LLO for a time as a mechanical engineer, part of the team that built Advanced LIGO.

Amber's and Derek's careers then took them back to Pennsylvania. Amber joined Villanova University's faculty in 2017, where she started an LSC group, and was promoted to Associate Professor with tenure in 2023. At Villanova, she was the PI of an NSF research grant and the Co-PI of an REU (Research Experience for Undergraduates) grant.

She was passionately dedicated to outreach and education as well as research, as demonstrated by the many positions she held in the community. She was the Informal Education/Public Outreach Lead for the LSC EPO group; an LVC Ally and member of coordination team; a former chair of the American Physical Society (APS) Forum on Informing the Public; former chair of the American Association of Physics Teachers (AAPT) Committee on Space Science and Astronomy; a former LAAC co-chair Member-at-Large (2021–2024): an elected member at large in the APS Forum on Education, and appointed member of the American Astronomy Association Committee on the Status of Women in Astronomy and the AAPT Committee on Women in Physics. As Louisiana adapted its high school physics curriculum to the new national standards, she was appointed to the state working group to do that work.

While in Louisiana, Amber was well connected with our community and a frequent patron of the Livingston Parish Library, a sponsor of Amber's TEDx talk on "Scientific Discovery in Your Backyard": https://www.youtube.com/watch?v=6CuYMkJPQKE

Amber was a rare scholar, helping bridge the gap between research and education at all levels. We will miss her dearly.

– Gaby and Joe –

by Gaby González & Joe Giaime

What does the Universe sound like?

Christopher Taudt aka harte echtzeit is a scientist during the day and a musician during nights. He received his PhD from the Technical University of Dresden, Germany in optical metrology and works mainly on interferometers for precise surface metrology. His interest as a musician is mainly in live coding music and exploring algorithmic structures in music. His music can be described as minimal, technoid musique concrète.

Typically we are surrounded by sounds we know: bells, claps, music, jingles, ticks and tocks. But when gravitational waves were measured for the first time and scientists announced that they are now able to “listen” to the universe, I became curious.

Possibly every one of us has some associations of what the void and open space may sound like and I guess a lot of it has to do with pop culture. Over decades, movies and music such as 2001 – A Space Odyssey or David Bowie have provided us with means to form a mental sonic image of space. But what was to be heard from the first 2015 LIGO observations was vastly different. Some even say boring. A solid bassy build up growing to a tiny, high-frequency chirp. Nothing more. But enough to trigger my imagination and curiosity.

History - no history

What actually sparked my interest even further were two things. First and foremost, these events occurred millions of years in the past and what reached us as a message somehow conveys the history of the event as well as the history of the journey. The second thing that striked me is the fact that what we hear is just a glimpse of the very last moments of an extremely powerful and violent event. The energy and the brutality cannot be imagined by any human.

We have barely any words, images or explanations for it and even our scientific knowledge is just evolving. That is a huge difference in terms of how we convey history. History in our cultures is very much tied to a human scale in its timelines, images and narratives. The history that gravitational waves and other cosmic events present us, is hard to grasp by means of our culture.

That's an aspect which triggered my attempt to make music purely from gravitational waves: capturing the vast journey, time and energy which encompasses a gravitational wave while also finding ways to speak with it in a human scale language. As a result, it led me to compose tracks which explore and experiment with sounds and soundscapes but also let rhythmic or melodic structures sneak in from time to time.

Musique concrète + live coding

The experimental part is integral to my work. I use a technique called live coding to work on sounds. That is basically programming software, but the code generates music. In my case, I work with a dialect called Tidal Cycles which has derived from the language Haskell. It makes it very easy to programme a line of code that repeatedly plays a sound. In that way, I can have the gravitational wave chirp be played over and over again. During this repetition, I can use some tricks and effects to manipulate the sound. Chopping the chirp slightly and playing it backwards emulates a good kick drum sound. By playing it back in quick repetition, I can generate a technoid four-to-the-floor phrase. As I can evaluate all changes immediately, live coding supports my curiosity and lets me experiment a lot. Even when I'm playing live, I experiment and no set is ever the same. The chopping and morphing of sounds is something which was introduced by the 1950s and 1960s already in genres like musique concrète and tape music. Usually, it involved field recordings of daily sounds like the clap of a door or the sound of a train whistle. At that time, it was new and avantgarde to use ordinary sound material like this to compose tracks using bits and pieces of magnetic tape that they were recorded on.

Today, I view data from experiments like LIGO, Virgo and KAGRA just as equally interesting for the composition of music. That's the reason I work in a similar fashion although more dynamic and live.

Today, I view data from experiments like LIGO, Virgo and KAGRA just as equally interesting for the composition of music. That's the reason I work in a similar fashion although more dynamic and live.

The album and playing live

During the last two years, I have composed a few tracks based solely on gravitational wave material. A few of these compositions ended up on the album ji kū kan which I have just released on September 14th 2024 ;-). It contains a mixture of tracks which vary between abstract sound compositions and more danceable, beat-like tracks. I tried to convey my interest and curiosity which I described earlier. During composition, I also always tried to think about the century-long scientific history of the gravitational waves starting with Einstein along with all of the very diverse attempts to measure them leading to the success of the observations. I had in mind the countless hours scientists spent on experiments, manuscripts, calculations and also on a lot of failures and setbacks. The mood of the album carries a little bit of this but also much of the joy the final discovery sparked. I play gravitational wave music live in clubs where people dance to it but also in art galleries and other places. One of my favourite gigs of last year was a show-and-tell session I did at the German detector GEO600 near Hannover. I was part of their open day and presented to people how to take the chirp and make a very basic techno track. It was a lot of fun and led to numerous great conversations about music, science and our human relation to both topics. I'm looking forward to playing at more occasions like this and especially getting to talk to more scientists about their work. For future music projects, I'd like to work with other gravitational sound sources such as from pulsar timing arrays.

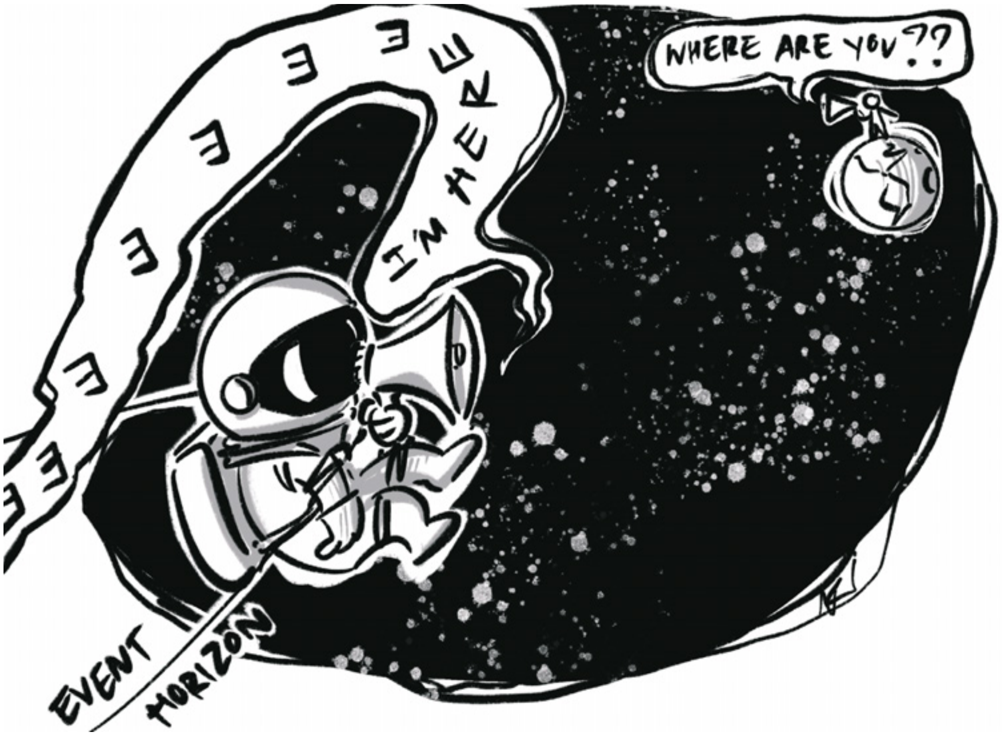
Tape edition of ji kū kan by harte echtzeit.

artist: harte echtzeit
album artist: harte echtzeit
album title: ji kū kan

song titles:
01 fabric (08:15)
02 tide (06:47)
03 duality (06:37)
04 superposition (08:58)

year: 2024

https://harte-echtzeit.com/
https://callitanythingrecords.bandcamp.com/album/ji-k-kan



An intrepid astronaut approaches a Black Hole.

Crossing the Event Horizon

Bartosz Fornal

is an assistant professor at Barry University in Miami, Florida. He is a theoretical particle physicist working within the LSC Stochastic Group on the search for primordial gravitational waves from first order phase transitions in the early Universe. In his free time, he enjoys swimming and playing beach volleyball.

Black holes are certainly the most mysterious objects in the Universe. They are regions of spacetime in which both space and time are warped so much that nothing, not even light, can escape their gravitational pull. The area of no-return is called the event horizon, and anything that crosses it becomes trapped inside the black hole forever.

Black holes were discovered as solutions to equations of Einstein's theory of general relativity by Karl Schwarzschild in 1916. However, it was not until 1939 when Robert Oppenheimer and his student, Hartland Snyder, demonstrated that they are not just a theoretical concept but can actually form after the collapse of a massive star. Their calculations revealed that when a sufficiently heavy star undergoes a supernova explosion, its core implodes forming an object with a horizon around it and a singularity at its center. By now, we have observed numerous black holes in the Universe.

The densities of black holes are enormous – if our Sun (of radius 700 thousand km) were squeezed to become a black hole, the horizon would have a radius of only 3 km! Most black holes that formed in supernova explosions have a few solar masses up to a hundred solar masses, however, most galaxies contain supermassive black holes at their centers with masses exceeding millions of solar masses.

What would happen to an astronaut travelling to the center of a black hole? Well, as with everything in the theory of relativity, it depends on the point of view! Let us first take the perspective of an observer far away from the black hole, and then analyze the journey as experienced by the astronaut.

Since spacetime becomes more warped as the astronaut approaches the horizon, time is passing slower closer to the black hole. (The fact that time flows slower when gravity is stronger must be taken into account by our GPS system, otherwise it would lose its accuracy quite fast!) For an outside observer it seems that the astronaut is slowing down to a standstill when approaching the horizon. If the astronaut is sending regular light signals while descending, those signals will be separated by longer and longer time intervals, also becoming redder and fainter. This can also be understood as light losing energy when climbing out of a region with a stronger gravitational pull.

At some point, when the astronaut is close to the horizon, the observer can no longer see the signals, since light does not have sufficient energy to escape the gravitational pull of the black hole. However, despite not being able to see the astronaut, the observer can still compute their position. A naïve calculation treating the black hole as a static object yields an infinite amount of time needed to reach the horizon, indicating that the astronaut is stuck there forever! If that were the case, how could anything fall into a black hole? More importantly, how could black holes even form, grow, and merge, which we know must be happening given our observations?!

A naïve calculation treating the black hole as a static object yields an infinite amount of time needed to reach the horizon, indicating that the astronaut is stuck there forever! If that were the case, how could anything fall into a black hole?

What is not taken into account in the reasoning above is that black holes are dynamical objects. When the astronaut is sufficiently close to the original horizon, the black hole increases its mass by the mass of the astronaut, at the same time enlarging its horizon! A precise calculation reveals that, in fact, a finite amount of time is needed for the astronaut to cross the horizon. Of course, it is still the case that light signals sent from a region very close to the horizon are so redshifted that we can never see them, and we certainly are not able to see the astronaut crossing the horizon.

The same applies to black hole mergers. An outside observer can never see the accreting gas pass through each of the black hole horizons, and they can never see the instant when the gas crosses the final merged black hole horizon. The only thing they see are two spheres of gas on their approach to becoming black holes, crashing together and behaving like a single sphere of gas on its approach to becoming the merged black hole.

Now, what does the journey look like from the perspective of the astronaut? Surprisingly, they experience it as an uninterrupted free fall without time ever slowing down! Depending on the size of the black hole, they may undergo stretching (spaghettification), since the gravitational force acting on their feet, if falling feet first, is larger than the gravitational pull on their head. This, however, is not a problem when falling into a supermassive black hole, since then the changes of the gravitational force at the horizon are less dramatic. If the astronaut is not paying attention, they may not even realize that they crossed the horizon – the point of no return!

Will each black hole grow by consuming nearby matter and then stick around forever? Not quite. In 1974 Stephen Hawking showed that black holes eventually evaporate (after a very long time) through a quantum process called Hawking radiation. Therefore, after all the matter in galaxies falls into supermassive black holes at their centers, and after those black holes evaporate, the Universe will ultimately be filled with just low energy photons – a pretty depressing fate!

In the meantime, black holes remain fascinating objects of theoretical exploration and are still hiding many secrets, including the information loss and firewall paradoxes. There also exist exotic solutions of general relativity equations allowing entangled black holes to be connected via wormholes, which act as bridges in spacetime connecting distant parts of the Universe. Finally, it is also hypothesized that the interior of each black hole might itself be a new Universe. Incidentally, the size and energy density of our Universe are roughly consistent with the corresponding parameters for a black hole the size of the visible Universe – could we be living inside a giant black hole?!

A precise calculation reveals that...

NASA reveals: Full-scale telescope prototype for LISA

LISA is a space-based gravitational-wave detector comprised of three spacecraft in a triangular constellation. LISA is scheduled for launch in 2035. The mission is led by ESA and is a collaboration between ESA, its Member State space agencies, NASA, and an international consortium of scientists (the LISA Consortium).

https://www.esa.int/Science_Exploration/Space_Science/LISA https://www.lisamission.org/

In October 2024, NASA has revealed the first look at a full-scale prototype for six LISA telescopes that will enable, in the next decade, the space-based detection of gravitational waves — ripples in space-time caused by merging black holes and other cosmic sources. Here, the prototype telescope undergoes post-delivery inspection in a darkened NASA Goddard clean room on May 20. The entire telescope is made from an amber-colored glass-ceramic that resists changes in shape over a wide temperature range, and the mirror's surface is coated in gold.

Text: NASA/Francis Reddy

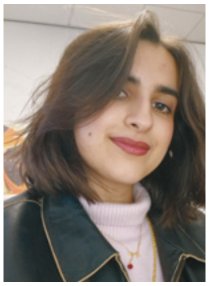
Image: NASA/Dennis Henry

https://science.nasa.gov/missions/lisa/nasa-reveals-prototype-telescope-for-gravitational-wave-observatory/

Empowering early career scientists to drive the next era of GW

The gravitational-wave (GW) field is evolving rapidly, bringing new and exciting challenges. In particular, we are approaching monumental changes in the structures of existing GW collaborations, the new detectors are entering an active phase of development, and there is general instability in the world. These challenges have the most impact on those who may not yet have the support of extensive community networks or the stability of a permanent position: early career scientists (ECSs). At the same time, our field is at a critical point where new mechanisms should be created that will allow us to address the challenges of years to come. These mechanisms rely on a strong community, but go beyond that, enabling flexible adaptation of personal connections and scientific tools to any future challenges. In this article we want to introduce you to one such mechanism: GWECS - gravitational-wave early career scientists organization.

Sama Al-Shammari



I'm a PhD student at Cardiff University working on gravitational-wave parameter estimation. My research focuses on applying machine learning techniques, particularly simulation-based inference, to improve how we extract astrophysical information from compact binary coalescences. I'm also one of the graduate student representatives in LAAC, where I help advocate for early-career researchers in the collaboration. If you are a graduate student within the LVK please do say hello and reach out to me if you need anything!

Mikhail Korobko

I'm a staff scientist at the University of Hamburg, Germany. I've been involved in early-career support for the most of my time as a scientist at different levels. I was a graduate representative in the LAAC, and since 2022 I'm co-chairing it. In 2021, I helped found the GWECS organization, and have been its coordination general since. I have two kids, who I spend most of my free time with (also early career support of sorts).

The GW field, unlike many others, is critically reliant on close collaboration between different sub-fields: ground- and space-based detectors, electromagnetic follow-up, theoretical studies, and data analysis. Many of these connections are tenuous, non-existent, or only exist at the very top of the scientific hierarchy. Current ECSs are the ones who will build and operate future detectors and create and develop data analysis and theoretical tools. These connections and mechanisms necessarily start with them, ensuring that new structures grow organically and evolve over the years in response to external and internal challenges. ECSs are in an unusual position: long-term decisions by their collaborations directly affect their future careers, but they have often had little say in these choices. The recent decision to

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include ECS representatives on the LIGO Council, following similar decisions taken by other collaborations, is a necessary and welcome step towards addressing this issue – graduate students and postdocs constitute about 45% of all LIGO Scientific Collaboration members. In each collaboration, there exists a dedicated support structure (such as LAAC in LIGO, VECS in Virgo and similar structures in KAGRA, LISA, ET, CE & PTA community) with a goal of addressing the needs of ECSs, creating links between different levels in the organization, providing learning tools, and enabling networking. However, moving forward, these structures will need to be reformed to better align with the changing landscape of GW science.

The question arises: what are the most important issues that such structures could address and what is the most impactful way they could be organized internally? For instance, LAAC consists of 8 people, addressing various issues directly, and VECS currently has 2 chairs who coordinate activities of all ECSs of the collaboration. The focus of these organizations could also be different: e.g., more on the networking and relation aspect, or on career development resources tailored to ECSs, or on developing and advocating for new policies benefiting ECSs.

While crucial for the work of the collaborations, these structures do not address the question of creating the mechanism that would allow us to sustain the GW field through all future challenges. To address this, we established GWECS (gwecs.org). It is an independent support structure that creates connections between people in different GW collaborations and promotes the creation of a common language, tools and knowledge towards the future of the GW field. All ECS support structures (from LIGO, Virgo, KAGRA, LISA, ET, CE, PTAs and any future organizations) form the GWECS Council which coordinates activities and actions across different collaborations. Several offices within GWECS are dedicated to particular issues, such as well-being and mental health, career opportunities, or science & research. Each office runs various activities involving individuals from different collaborations, building critical tools that work outside the direct influence of any specific collaboration, towards the joint success of GW science.

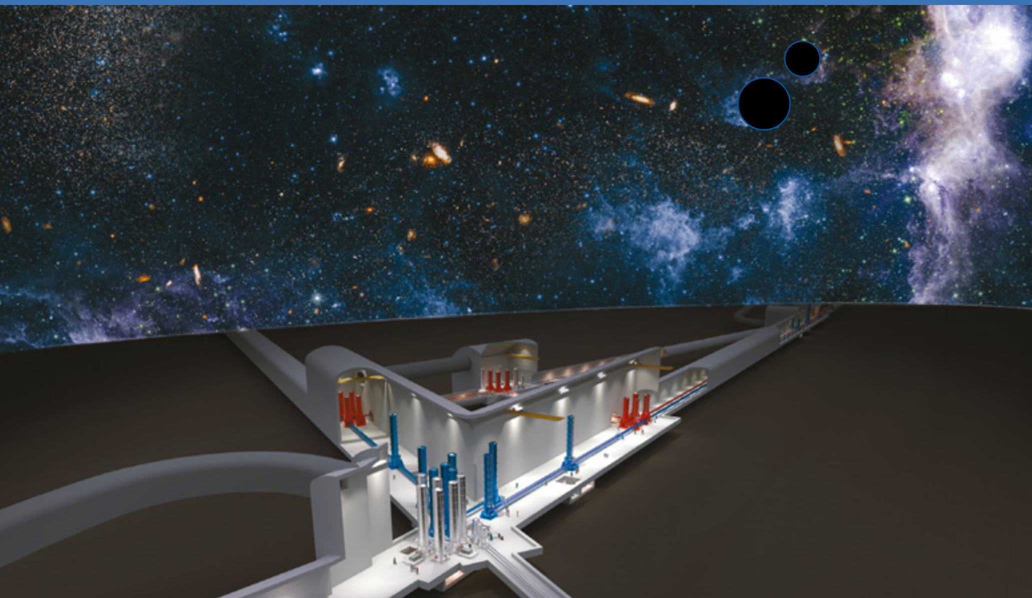
Among other things, GWECS holds yearly job fairs, hosting ~150 people each year, and maintains a list of open positions and grants: gwecs.org/career. As an important way to bring ECSs together and help them find common language, GWECS organizes ECS-targeted workshops[1]. We hope to see you at the next one in Glasgow in July 2025! iop.eventsair.com/gr24-amaldi16/

While many aspects of our scientific lives may seem established and immutable, we have the power to create a better future for ourselves and for science. Therefore, your opinion and contribution matter even in small things, moving us towards this common goal. Get in touch with us if you have any ideas or suggestions or if you want to join our work: https://gwecs.org.

LIGO 2025

We have the power to create a better future for ourselves and for science. Your opinion and contribution matter even in small things, moving us towards this common goal.

[1] *Bayle et al., 2022, "Workshop on Gravitational-Wave Astrophysics for Early Career Scientists"* https://www.nature.com/articles/s41550-022-01629-8



In an early phase, comparable European projects are usually run by scientists, while professional managers and engineers are only hired after the implementation phase is well underway. This can create a lack of expertise in the early phase, and thus delays. The Einstein Telescope Organisation tries to do this differently, by creating a professional non-scientific organisation early on, to coordinate and organise the Einstein Telescope project.

The Einstein Telescope Organisation

While the LIGO, Virgo and KAGRA detectors are collecting data, plans for next-generation observatories, like the Einstein Telescope (ET) and Cosmic Explorer are being made. Bringing these plans to life requires vision, coordination, and dedicated efforts. In Europe, many scientists, engineers and professionals are working hard to make this happen. And the Einstein Telescope Organisation (ETO) plays a crucial role.

ETO is steadily working to transform the Einstein Telescope from an idea into reality, acting as a pivot, right in the middle between the Einstein Telescope Scientific Collaboration and the 'local teams' of the potential sites where the observatory might be built. The Einstein Telescope Organisation coordinates processes, but also fosters collaboration among an incredible variety of experts. From scientists, engineers and project managers to architects, financial coordinators and communicators, ETO brings together a diverse group of professionals working towards a shared goal.

Josep (Pep) Freixanet is a communication officer for ETO and based at IFAE in Barcelona. When he is not communicating about science, he sometimes ends up being a part of human towers.

Martine Oudenhoven is head of the communication office of ETO and based at Nikhef in Amsterdam. As a communication strategist for science, she often works on the 'invisible part' of communication. Her hobbies include yoga and gardening.

ETO currently consists of 36 people (and growing!) with very diverse back grounds located across Europe. It is led by directors Andreas Freise and Fernando Ferroni. The organisation works remotely on a daily basis, but meets in person regularly as well for specific or general meetings.

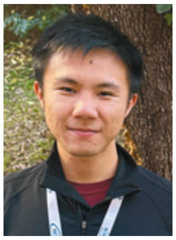
Challenges of a Growing Organisation

One of the people contributing to this effort is **Addis Koeck**, a recent graduate working as a financial coordinator. His role involves helping to structure the directorate, supporting management, and ensuring that the evolving organisation remains functional and efficient. "One of the biggest challenges is the dynamic nature of ETO," he explains. "We are constantly defining roles and responsibilities as we grow."

But Addis sees beyond the internal structure—he recognizes the broader impact of the ET project. With interdisciplinary collaboration at its core, ET brings together geologists, engineers, and physicists to push the boundaries of science. Moreover, its presence in the host region could boost education and STEM opportunities, bringing long-term economic and scientific benefits.

The Role of Geotechnical Engineering

The Einstein Telescope is to be built underground to shield it from external noise, so understanding the subterranean landscape is critical. That's where **Jonathan Bratanata**, a geotechnical engineer at ETO, steps in. His job is to assess rock formations, soil quality, and water presence to determine the feasibility of the infrastructure.



"Building something like the Einstein Telescope underground presents unique engineering challenges," Jonathan says. "Extensive drilling and feasibility studies are needed to make sure the chosen location is viable." Beyond the technical challenges, Jonathan emphasizes how ETO plays a key role in uniting experts from different fields. "ET has been discussed for decades, and ETO is pushing hard to fully bring it to fruition. We connect the right people, coordinate their efforts, and ensure that progress is made efficiently." For Jonathan, projects like the Einstein Telescope are exciting not just because of their scientific significance but because of the unexpected technological innovations they bring. He also values the diverse and international nature of ETO. "There are so many perspectives, and that makes collaboration interesting—though it can also be a challenge when different opinions come into play!"

The Power of Interdisciplinary Thinking

Few people embody the spirit of interdisciplinary collaboration better than **Ghada Mahmoud**. With a background spanning civil engineering, mechatronics, and optics, she now works on systems engineering for ET. Her career path highlights the importance of blending different disciplines to tackle complex scientific challenges. "Large-scale projects like ET require a strong project culture to ensure smooth collaboration," Ghada explains. "The challenge isn't just technical—it's about coordinating teams across multiple countries and integrating new low-frequency technologies into the design."

She also sees young scientists and engineers as essential to ET's success. "Their enthusiasm and fresh ideas, combined with the experience of senior researchers, help drive innovation," she says. By fostering a culture that welcomes new talent, ETO hopes that ET won't just be a state-of-the-art observatory but also a training ground for the next generation of scientists and engineers.

Structuring an International Collaboration

When it comes to large-scale scientific collaborations, few people have more experience than **Roberto Saban**. After 43 years at CERN and INFN, Roberto now contributes his expertise to ETO, helping to shape its structure and assemble a capable team.

While he is excited about the scientific and technological frontiers ET will push, Roberto is also focused on the human and organisational aspects. "One of the main challenges is creating synergy among teams and establishing a structured hierarchy that fosters both accountability and pride in our collective mission," he says.

For Roberto, one of the most rewarding aspects of his work at ETO is mentoring young scientists. He hopes to help build a "dream team" similar to the one that commissioned the LHC's technical systems. "It's incredibly inspiring to see a new generation of scientists and engineers take on a project of this magnitude," he adds.

Turning ambition into reality

The Einstein Telescope is an extraordinary scientific endeavor and ETO is working steadily to turn this ambitious concept into a reality. This may even shape the way international collaborations function in the future.

With a team that includes financial coordinators, geotechnical engineers, interdisciplinary researchers, and seasoned project leaders, we are showing that groundbreaking science is not just about physics—it's about people. Through combined expertise, dedication, and passion, we are helping pave the way for the Einstein Telescope.

Cooling all Mirrors

04 →

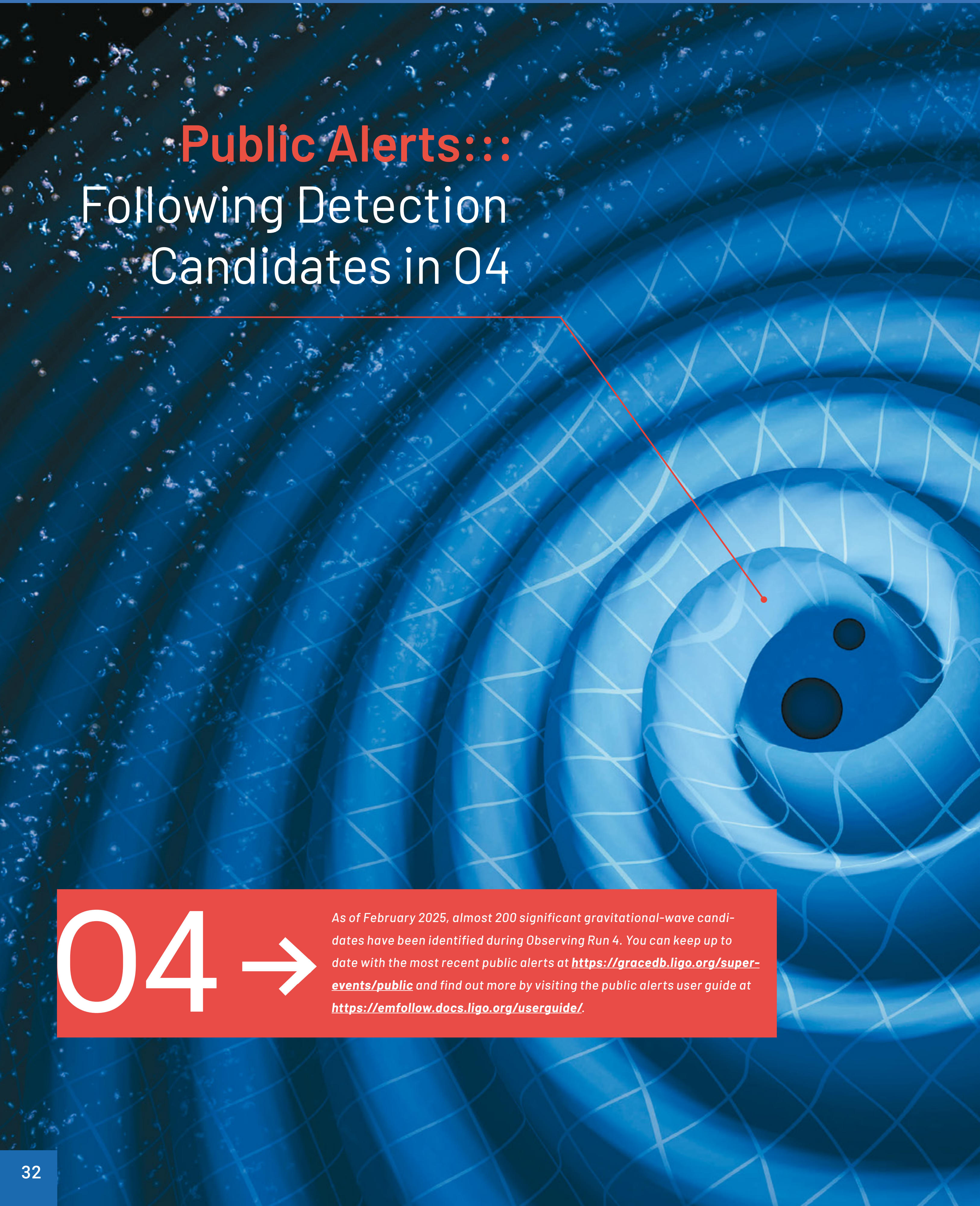
After the damage of the Noto Peninsula earthquake (Jan 1, 2024; Magnitude 7.6; 100km away from KAGRA), KAGRA spent 11 months recovering. Now commissioning is ongoing. All the mirrors are now cooling down to targeted temperature, 80–90K (as of Feb 28). The standard temperature of KAGRA facilities is around 22 degrees Celsius, while the outside of the tunnel goes below freezing. This year, the north side of Japan has quite heavy snow. From January, the site area normally has 100 cm depth of snow.

– Eri Sakamoto & Hisaaki Shinkai –

Big Bang Machine

The van 'Big Bang Machine' is a mobile immersive installation, curated by EGO with the support of Fondazione Pisa, IVECO and the European Union project AHEAD 2020, which takes visitors on a virtual journey through space and time to the origin of our Universe.

Collega-menti Festival



Public Alerts:::
Following Detection Candidates in O4

O4 →

As of February 2025, almost 200 significant gravitational-wave candidates have been identified during Observing Run 4. You can keep up to date with the most recent public alerts at ***https://gracedb.ligo.org/superevents/public*** *and find out more by visiting the public alerts user guide at* ***https://emfollow.docs.ligo.org/userguide/****.*

Searching for Systematics in Banking

I have had a long relationship with the LIGO collaboration, having joined it in the autumn of 2013. However, after a decade in this field, I decided to opt for a change of careers, mostly due to wanting some stability after having a kid. Honestly, I had no clear idea of which sector in the corporate world I would like to move to nor how to write a CV more tailored for the corporate world. Let's be honest, "worked on systematics of GW150914 due to waveform model inaccuracies" is not something most people would get; but "experience in quantifying systematic errors arising from various sources" is something most people can work with. With a few online certifications and a fancier sounding yet the same CV; I ventured into applying for any job that required statistical analysis, model development, machine learning etc.

Chinmay Kalaghatgi here, a former gravitational-wave dude turned banker trying to figure out a way through the corpo world while working at ABN AMRO. While I'm not working, I entertain my kid, enjoy playing the Bansuri (Indian bamboo flute), playing on my PlayStation or making up bad dad jokes. For eg: What's the most spiritual foodstuff?

The Auummlet

After a few interviews and from the input of a colleague, I decided to join the Credit Risk Analysis department of the ABN-AMRO bank located in Amsterdam. Currently, I work in the Non-retail Model Monitoring and Strategy department. Basically, banks are required to hold 'X' amount of capital based on whatever 'Y' amount of exposures they have and this 'X' amount can be determined by models. Banks are required to test these models regularly to determine their viability towards their use for the given problem. Sounds similar, doesn't it?

I have been here at my role for more than a year now and I have been enjoying it. There were a few challenges to face during the start; the most important one being understanding the banking sector. However, a few internally available courses and learning on the job enabled me to start working independently within six months of joining. The things that I really like about the new role are a much better work-life balance (no more calls at 6.00 a.m.) and job security (no more moving to a new country for a postdoc). Having a very friendly team from diverse backgrounds provides a great support system within the company and leads to very interesting conversations.

All in all, stepping away from my comfort zone of Gravitational Waves was quite daunting and scary at first. But, as people trained in LIGO, we possess highly transferable skills that are more in-demand than one might expect. For starting positions, a deep understanding of a given sector is as desirable as a mathematical and programming acumen. So, for someone who might be thinking of taking the plunge, it's not as scary as it seems at first; but you will always miss the LVK Meeting parties.

- Chinmay Kalaghatgi -

We hear that ...

Career Updates

Aditya Vijaykumar defended his Ph.D thesis "Probing gravity, astrophysics, and cosmology with gravitational waves". https://thesis.icts.res.in/thesis/ICTS-1710150189

Bikram Keshari Pradhan successfully defended his PhD thesis from Inter-University Centre for Astronomy and Astrophysics (IUCAA, Pune) on 14th November 2024 and joined as a postdoctoral at IP2I Lyon, France .

Graeme Eddolls will be finishing his postdoctoral position at Syracuse University in April 2025 and he is moving to Washington DC to work at NASA Goddard Space Flight Center on the LISA Telescope Team from June 2025.

Kentaro Somiya from the Institute of Science Tokyo joined OzGrav as an Associate Investigator and he is now based at ANU until Mar 2026. Prof. Somiya works on project ASPIRE-GW, which supports researcher exchanges between Australia and Japan: https://aspire-gw.com/

Marek Szczepańczyk got a permanent faculty position at the University of Warsaw and received a special Polish Returns award (comparable with a US NSF CAREER award) to build his research group and continue working on the GW bursts analyses: https://www.fuw.edu.pl/~mszczepanczyk/

Natalie Williams has defended a PhD titled ''Gravitational Wave Modelling and Analysis for Binary Neutron Star Inspirals" at the University of Birmingham, UK, and has now started a new role at Universität Potsdam, Germany, as a Postdoctoral Researcher.

Ornella Juliana Piccinni (The Australian National University) has been awarded the prestigious "Ramón y Cajal" Fellowship by the Spanish Ministry of Science. She will start her term in September this year at the Institut de Física d'Altes Energies (IFAE) in Barcelona. This Fellowship grants a tenure-track position in any Spanish University or Institute that the recipient chooses.

Pablo Barneo defended his Ph.D. thesis on January 19, 2024, at the ICCUB, University of Barcelona, Spain. His research on "Denoising of Gravitational-Wave Data: the rROF Method in the cWB Data Analysis" is focused on the implementation of the rROF denoising method in the cWB pipeline to improve the detectability and analysis of gravitational signals in current and future data acquired by the LVK collaboration. He is currently a postdoc researcher at the ICCUB research institute, where he will continue his work on gravitational-wave data analysis for the GW group in his institution.

Suprovo Ghosh successfully defended his PhD thesis from Inter-University Centre for Astronomy and Astrophysics (IUCAA) on 14th January 2025 and joined as a postdoctoral fellow at the University of Southampton, UK.

Verónica Villa Ortega successfully defended her Ph.D. thesis at the University of Santiago de Compostela in September 2024 with Sobresaliente cum laude.

Awards

Aditya Vijaykumar received the Justice Oak Award for Outstanding thesis in Astronomy for the year 2024 by the Astronomical Society of India and V. V. Narlikar Best Thesis Award for the year 2024 by the Indian Association for General Relativity and Gravitation.

Elisa Maggio, a Marie Curie Fellow at the Max Planck Institute for Gravitational Physics in Potsdam, will receive two prizes. The Italian Physical Society named her the winner of this year's Laura Bassi Prize for early career women in physics. She will also receive one of the 2023 thesis prizes from the Sapienza University of Rome. https://www.aei.mpg.de/1180374/elisa-maggio-wins-laura-bassi-prize-and-thesis-award

Gustav Uhre Jakobsen, a postdoc at the Humboldt University of Berlin and at the Max Planck Institute for Gravitational Physics in Potsdam, will be awarded a "Tirburtius Prize – Prize of the Berlin Universities" for his dissertation "Gravitational Scattering of Compact Bodies from Worldline Quantum Field Theory". https://www.aei.mpg.de/1202051/tiburtius-prize-2024-for-gustav-uhre-jakobsen

Maya Fishbach was awarded the Annie Jump Cannon Award in Astronomy "for major contributions to the field of gravitational-wave astrophysics and cosmology." https://aas.org/grants-and-prizes/annie-jump-cannon-award-astronomy

Purnima Narayan was awarded the 2024 Grand Prize Winner of the 3 Minute Thesis (3MT) competition by the University of Mississippi. It is awarded to one graduate student annually from the entire university in a research communication competition, wherein they presented their work on "Testing Einstein's Theory with Cosmic Collisions".

Susan Scott (Distinguished Professor at the Centre for Gravitational Astrophysics, ANU) has been awarded the Australian Mathematical Society's most prestigious award - the George Szekeres Medal - at a joint meeting with the American Mathematical Society and New Zealand Mathematical Society held in Auckland.

Suvodip Mukherjee, Tata Institute of Fundamental Research, Mumbai has received the N. R. Sen Young Scientist Award, 2024 for his contribution in astrophysics, cosmology, and gravitational physics.

Swarnim Shirke has won the Special Award for excellent presentation at the CSQCD (Compact stars in QCD Phase Diagram) conference on 11th Oct 2024 at the Yukawa Institute of Theoretical Physics in Kyoto, Japan.

The **European Pulsar Timing Array** team will receive a "Group Achievement Award" from the Royal Astronomical Society. Among the honored researchers are scientists from the Max Planck Institute for Gravitational Physics. https://ras.ac.uk/news-and-press/news/pioneering-physicist-and-galaxy-luminary-among-2025-ras-award-winners and https://ras.ac.uk/sites/default/files/2025-01/European%20Pulsar%20Timing%20Array%20-%20Group%20Achievement%20Award%20%28A%29.pdf

New LSC positions

The LAAC (LSC Academic Advisory Committee) election results are: **Amanda Baylor** has been re-elected as graduate student representative, **Begüm Kabagoz** has been elected as postdoc representative, **Jessica Steinlechner** was re-elected as Senior member and **Mikhail Korobko** has been re-elected as co-chair.

François Schiettekatte has been re-elected as Optics working group co-chair.

Kate Dooley has been elected as Technical Advisor to the Oversight Committee.

Other News

Deirdre Shoemaker was elected APS Councilor for the Division of Gravitation, where **Laura Cadonati** is still serving as elected General Councilor. **Gabriela González** was also elected Vice-President of the APS. https://www.aps.org/about/governance/general-election

Mark Scheel (Caltech) and **Xavier Siemens** (Oregon State University) were elected 2024 American Physical Society Fellows (a great honor, recognizing excellence in physics and exceptional service to the physics community). https://www.aps.org/funding-recognition/aps-fellowship/dgrav-fellowship

The **Max Planck Institute for Gravitational Physics in Potsdam** is one of the four partners in the international consortium “GWSky”, which the European Research Council has awarded 12 million euros to develop a deeper understanding of gravitational waves. https://www.aei.mpg.de/1190686/making-sense-of-the-unexpected-in-the-gravitational-wave-sky

The **Max Planck Institute for Gravitational Physics in Potsdam** is one of the four partners in a European Research Council funded project. The institutions will receive 10 million euros for research into a comprehensive theoretical framework relevant for predicting experimental results from particle accelerators and gravitational-wave detectors. https://www.aei.mpg.de/1190906/understanding-elementary-particles-and-black-holes-with-modern-mathematics

The **2025 Gravitational Wave Advanced Detector Workshop (GWADW)**, a one-week event dedicated to exploring the future of the detection of gravitational waves, takes place 18 to 23 May 2025 at the Hilton Cocoa Beach (Florida) Oceanfront. GWADW 2025 will follow the style and traditions of earlier detector workshops, going back to Aspen in the 1990s.
Website: https://gwadw.clas.ufl.edu/.
If you have questions, please send them to tanner@phys.ufl.edu.

Hope to see you there!
John Conklin, Paul Fulda, David Tanner

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The ETO team meets at Nikhef in 2024

Control loops are the information → instruction cycles used to keep the detector at a certain set point that is suitable for gravitational-wave detections. For example, we need the mirrors to stay still and not move. We set our required set point for stillness, then a sensor looks at the mirror, sends some information to a device which applies a force to restore the set point, if any variation happens.

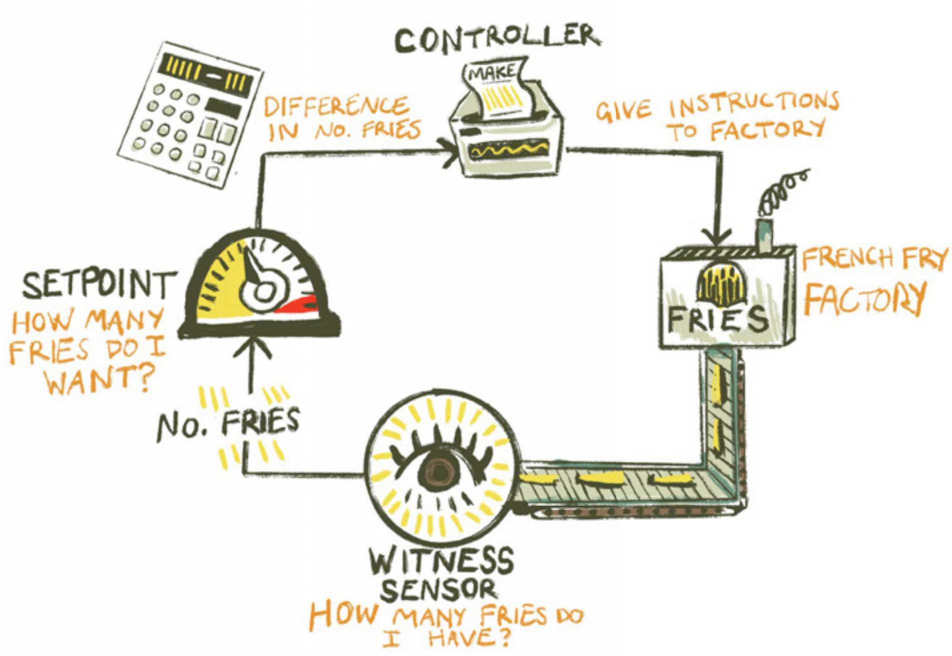
How do control loops work in practice? Jenne Driggers at LIGO Hanford Observatory developed an intuitive, yet precise analogy to explain the concept in detail. It is called the French Fry Factory.

In this scheme, our set point is the number of fries we want out of the factory. The factory makes fries and at its exit we deal with a certain number of them. Then a witness sensor looks at this number, counting fries. The display shows how many fries we have got and sends the information out. If the number of fries is different from our set point, this is sent as an error signal to a device called Controller, which makes the decision on how to fix the error. Then it communicates the decision to the factory, which adjusts the production and gives the number of fries we requested, and the loop restarts.

This loop is applied to anything that needs to be controlled, from laser power, to squeezed light, to motion of mirrors. The set point for each of these quantities is chosen by the sensitivity requirements of the detector.

The control engineers constantly make sure the loops work with no troubles. The implementation of a new loop is never straightforward: any other installation must not interfere with the existing loops. This requires approval by the administration to avoid damage to the control loops or other possible issues when significant changes are made.

Not an easy job to get the fries we want, with the sauce we want and the drink we want! :D



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by Chiara Di Fronzo, illustrated by Storm Colloms