



LIGO
Scientific
Collaboration



LIGO MAGAZINE issue 10 3/2017

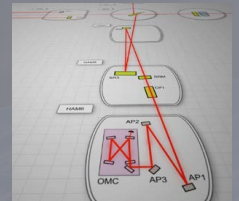
02: A new season!

03:38:53 UTC, 30 November 2016



Getting ready for O2: The Data Analysis Perspective

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To Catch a Wave

A LIGO Detection Story p.18



and an interview with former NSF Director Walter Massey on LIGO's early days.

Before sunset, along one of the 4km long arms, LIGO Hanford Observatory, WA, USA.
Photo courtesy Keita Kawabe.

Inset of optical layout: Still image from the documentary “LIGO Detection” provided by Kai Staats.

Inset of Joshua Smith: Still image from the documentary “LIGO Detection” provided by Kai Staats.

Image credits

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Antimatter





Jocelyn Read

Welcome to the tenth issue of the LIGO Magazine. This issue comes as we enter a “new season” of gravitational-wave astronomy: continuing the search for new signals with LIGO’s second observing run, “O2”. We begin with an overview of O2 and an interview, “Getting ready for O2: A data analysis perspective”, with gravitational-wave astronomers Sarah Caudill and Vivien Raymond when they were gearing up to begin analyzing the new data. Michael Zevin discusses the new “Gravity Spy” citizen science project, which is drawing insight from thousands of volunteers to characterize new LIGO data. And, as we prepared LIGO for O2, our colleagues were making exciting progress towards space-based detection of gravitational waves, outlined in “LISA in Brief”. Looking back to the groundwork that made modern-day gravitational-wave astronomy possible, we also interview Walter Massey about his time as NSF Director when the LIGO project was first approved.

The impact of our first gravitational-wave detections continues to ripple outward, and in this issue we feature some of the artistic work they’ve inspired: “Infinite LIGO Dreams”, by Penelope Rose Cowley, the poem, “What I think about when I think about gravitational waves”, by Ananda Lima, and a behind-the-scenes look at the making of the LIGO detection documentary by Kai Staats. Finally, we also share some more personal stories of career navigation from folks who started as LIGO and Virgo students or postdocs: Brynley Pearlstone shares his experience as a LIGO Fellow, Conor Mow-Lowry outlines his recent path to an astrophysics faculty position, and eight LIGO or Virgo collaboration alumni – Alberto Stochino, Justin Garofoli, Eleanor Chalkley, Laleh Sadeghian, Ludovico Carbone, Nicholas Smith, Patrick Kwee, and David Yeaton-Massey – discuss how they moved from their academic work and training into a wide range of careers in industry and business.

This is the first issue since I’ve taken over as editor-in-chief of the LIGO Magazine, and it’s been rewarding to see the Magazine come together thanks to the hard work of the full editorial team and the invaluable guidance and advice of outgoing editor-in-chief Andreas Freise. Andreas has made the LIGO Magazine a centerpiece of collaboration communication over the last five years, and I’m looking forward to continuing this legacy. As always, for the Magazine to be interesting and relevant we rely on all of your input and suggestions. Please send comments and ideas for future issues to magazine@ligo.org.

Jocelyn Read for the Editors

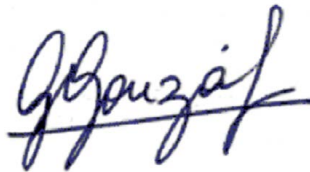


LIGO Scientific Collaboration News

This is the last time Marco and I write this magazine introduction as LSC spokesperson and assistant spokesperson. It has been an honor and a pleasure to lead the LSC during these very exciting years, and we thank all of you for making this collaboration not just successful, but also a great community to work with. I will admit that the editors of the magazine, including the first past editor, Andreas Freise and the new editor, Jocelyn Read, have been among our favorite people to interact with.



Gaby (Gabriela) González
LSC spokesperson

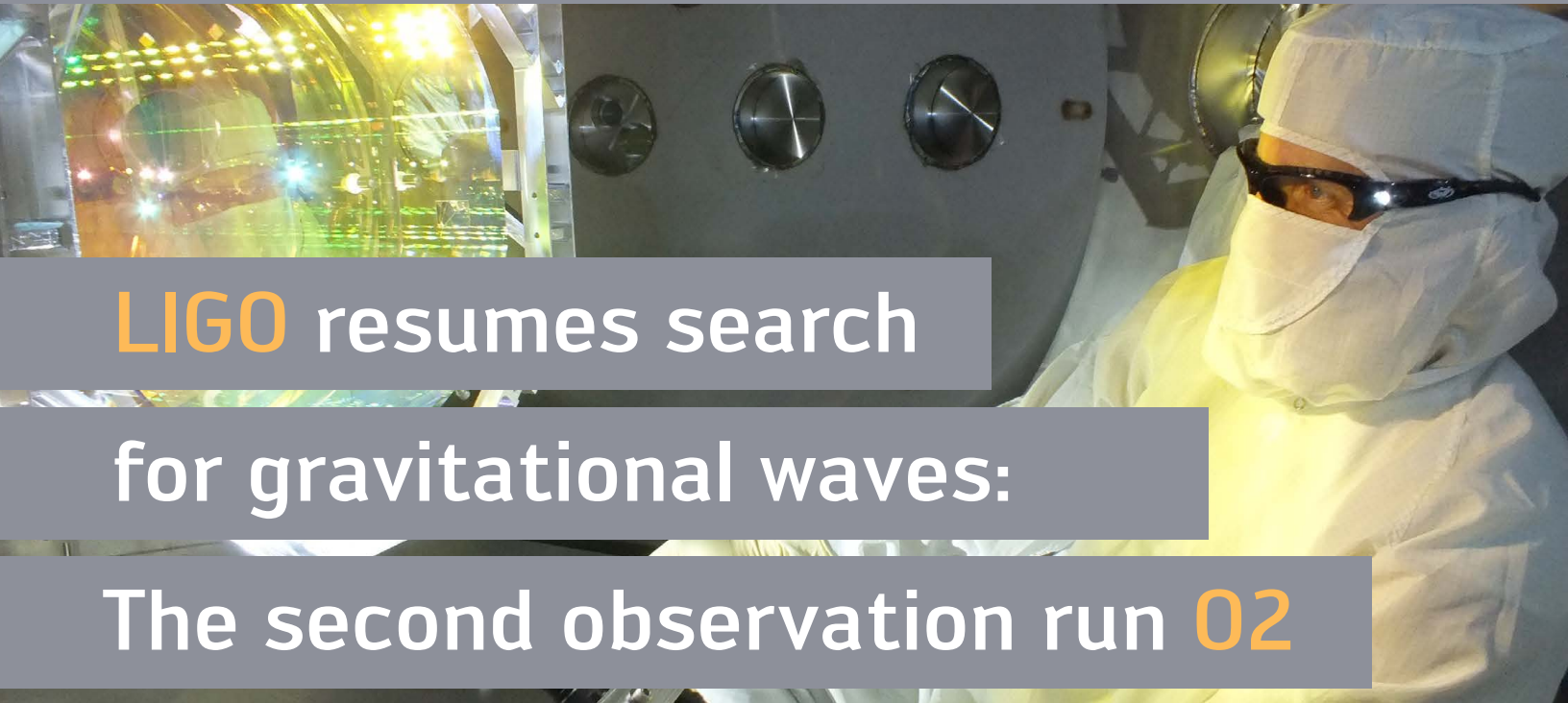


We want to thank you all for the work contributed to the Collaboration, especially to those who did the very important but often thankless jobs that made the first and second detections possible - from designing, building, diagnosing and operating the detectors, to debugging and running and reviewing the data analysis codes and results, to help writing and reviewing not just the detection paper but the many other papers we wrote before and after. Thanks to all of you who volunteered for providing service to the LSC committees and chairing working groups and subgroups that help us do our science by keeping us organized and running smoothly - not only we thank you, but we hope you inspire the rest of us to follow your example.

As we keep singing the LSC chirp of the past detections and the many to come, let's celebrate our teamwork, and keep up the good job. This is the beginning of a new era, and there's a lot still to do!

THANK YOU!

Gabriela González and Marco Cavaglia



LIGO resumes search

for gravitational waves:

The second observation run 02

An Advanced LIGO test mass at the Livingston detector. To reduce scattered light, there can be no contamination on any optical surfaces.

3 0 November 2016 - O2 begins. After a series of upgrades, the twin detectors of LIGO have begun their second science observing run, commonly referred to within the collaboration and in publications as “O2”. What can we say about O2 so far?

In 2016, the LIGO Scientific Collaboration (LSC) and the Virgo Collaboration announced two gravitational-wave detections from merging black holes. Those initial detections were made during LIGO’s first science observing run, called “O1”, which lasted from September 2015 to January 2016. Engineers and scientists from the international collaboration then spent much of the year evaluating LIGO’s performance and making improvements to its lasers, electronics, and optics. The twin LIGO detectors transitioned from engineering test runs back to science observations at 8 a.m. PST on November 30, 2016. As the detectors turned on in November, the Livingston detector had about a 25 percent greater sensitivity – or range for detecting gravitational waves from binary black holes – than during the first observing run. The sensitivity for the Hanford detector was similar to that of the first observing run.

“The Livingston detector has improved

sensitivity for lower gravitational-wave frequencies, below about 100 hertz, primarily as the result of reducing the level of scattered light, which can be a pernicious source of noise in the interferometers”, said Peter Fritschel, LIGO’s chief detector scientist, at the start of O2. “This is important for detecting massive systems like the merger of two black holes. We are confident that we’ll see more black-hole mergers.”

“LIGO Hanford scientists and engineers have successfully increased the power into the interferometer, and improved the stability of the detector”, said Mike Landry, the head of LIGO Hanford Observatory, at the start of O2. “Significant progress has been made for the future utilization of still higher power, which will ultimately lead to improved sensitivity in future runs. Furthermore, with the addition of specialized sensors called balance-beam tilt meters in the corner and end stations, the detector is now more stable against wind and low-frequency

LIGO Scientific Collaboration and Virgo Collaboration



▲ *A panoramic shot of lead operator Corey Gray's view during an overnight shift at Hanford.*

seismic motion, thereby increasing the amount of time the detector can be in observing mode.”

As of January 23, approximately 12 days of Hanford-Livingston coincident science data had been collected, with a scheduled break between December 22, 2016 and January 4, 2017. For binary mergers, the reach of the detectors changes with the masses of the binary; the average reach of the LIGO network has been around 300 Mpc for mergers of black holes 10 times the mass of our sun (or 10 solar masses), and 700 Mpc for mergers of 30 solar mass black holes. For mergers of two 1.4 solar mass neutron stars – the dense cores of exploded stars – the average reach has been 70 Mpc. Detector sensitivity varies in time, with relative variations of the order of 10%.

In that first stretch of O2, two event candidates, identified by online analysis using a loose false-alarm-rate threshold of one

per month, were identified and shared with astronomers who have signed memoranda of understanding with LIGO and Virgo for observational follow-up. A thorough investigation of the data and offline analysis are in progress. As O2 progresses, status updates will regularly be posted on <http://ligo.org/news/>.

An upgraded Advanced Virgo detector expects to join the LIGO network in science observations in 2017, potentially bringing significant improvement to our ability to localize the sources of detected signals on the sky. The LIGO and Virgo teams will continue to improve the observatories' sensitivities over the coming years, with increases planned for each successive observing run. As more black-hole mergers are detected, scientists will start to get their first real understanding of black-hole pairs in the universe – including their population numbers, masses, and spin rates. We may also detect the merger of neutron stars.

“LIGO’s scientific and operational staff have been working hard for the past year and are enthusiastic to restart round-the-clock observations. We are as curious as the rest of the world about what nature will send our way this year”, said LIGO Livingston Observatory head Joe Giaime of Caltech and Louisiana State University.

“For our first run, we made two confirmed detections of black-hole mergers in four months. With our improved sensitivity, and a longer observing period, we will likely observe even more black-hole mergers in the coming run and further enhance our knowledge of black-hole dynamics. We are only just now, thanks to LIGO, learning about how often events like these occur”, said Caltech’s Dave Reitze, executive director of the LIGO Laboratory, which operates the LIGO observatories.



Getting ready for 02: A data analysis perspective

▲
New high-performance computing cluster at the Albert Einstein Institute, Potsdam

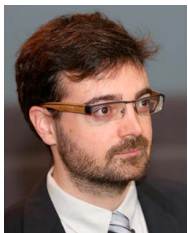
Sarah Caudill



is a postdoctoral researcher in the Center for Gravitation, Cosmology, and Astrophysics at the University of Wisconsin-Milwaukee. She enjoys breaking up long research sessions with spon-

aneous dance parties and has recently been learning to drive her electric car in the snow.

Vivien Raymond



is a researcher at the Max Planck Institute for Gravitational Physics in Potsdam, Germany, and a co-chair of the Compact Binary Coalescence Parameter Estimation group. Vivien is involved in

another long-term, multi-disciplinary project heralding a new era: his 11-month old daughter Elinor.

The second Advanced LIGO observation run 02 began on November 30, 2016 and is currently in progress. As of January 23 approximately 12 days of Hanford-Livingston coincident science data have been collected, with a scheduled break between December 22, 2016 and January 4, 2017.

After the flurry of activities in the winter and spring, how did you transition back to work for 02?

Sarah: It took a little bit of time to transition. I went from having daily meetings with Laura Nuttall and Mike Landry to get the GW151226 paper published by June 15, giving talks at three conferences in May and June, and teaching astronomy lectures during the spring semester to having actual free time. I really enjoyed that, but of course, the nagging feeling of wanting to dive back into research reared its head before too long. The folks working on the gravitational wave detection pipeline “gstlal” commenced having daily meetings starting in the summer. Since

one of our lead developers, Kipp Cannon, had just moved to Japan, we were meeting at 6-7am in the morning sometimes. That was tough!

What’s the hardest part of transitioning from an old project to a new one?

Vivien: Letting go of the old one! I’m always working on multiple projects in parallel, often too many at a time (it seems I’m not alone in that...), and most of the time they have the potential to continue and transform into long-term quests for answers. But with 02 coming, priorities had to be made, and I’m lucky to work with very competent colleagues so we can work on many things together.

What sort of 02 research activities have you been working on?

Sarah: I had a lot of fun this summer working with Cody Messick exploring adding new parameters to the gstlal likelihood ratio ranking statistic for 02. We had not previously included the phase or timing information of coincident matched filter



▲ High density Intel Skylake CPU systems installed in the aLIGO datacenter at Caltech to analyze data O2 data.

triggers as factors in this statistic. I got very well acquainted with von Mises distributions and Chebyshev polynomials, and then promptly forgot all about them at the conclusion of the project. I have also been testing the new `gstlal` configurations with Duncan Meacher and continually bugging him for help when I run into code installation issues.

Did you enjoy your summer?

Vivien: Very much so! The Compact Binary Coalescence Parameter Estimation team started with a face-to-face meeting in Boston, where we laid out our goals and timelines for O2. Then it was all about making it happen! That, and the many speaking opportunities: it seems everybody wants to hear about gravitational waves, from elementary school groups to international research teams. That made for a great, and busy summer.

Have you been working with any new scientists/research groups?

Sarah: We've had an influx of new gradu-

ate students and postdocs here at University of Wisconsin-Milwaukee. It's been exciting to watch their progress over the last few months from just starting to learn the ropes of LIGO data analysis to taking command of their own project. I enjoyed learning with new members Koh Ueno and Deep Chatterji how to construct an event processor to interact with the Gravitational-wave Candidate Event Database, GraceDB. And Shasvath Kapadia, Heather Fong and I spent lots of time learning how mass-weighting can be used to rerank candidate events and improve astrophysical rate estimates.

Compare your state of mind before O1 to now, at the beginning of O2.

Vivien: There's some of the same excitement, making sure everything works (and fixing what *sometimes may not work perfectly*). But of course I'm approaching this new observing run differently. The window has been opened, we are actively probing the universe for answers. It was never a question of *if* with LIGO, always

when. But now the time-scale is months, not years!

Have your research methods changed at all since a year ago?

Vivien: We are using a different likelihood function for some of our most computationally expensive waveform models, based on Reduced Order Modelling. We have also improved our handling of the uncertainty in taking into account noise properties, for instance more robustly fitting for the power spectral density. And we scaled the parameter estimation algorithms to handle a much quicker turnaround than in O1...

What are your predictions for O2 discoveries?

Sarah: Of course we will see more binary black hole gravitational waves! I'm rooting for a signal from a binary neutron star inspiral with an electromagnetic counterpart. What a great way to further solidify the community's confidence in our detections!

The Gravity Spy Project: Machine learning and citizen science

Gravity Spy is a project to integrate LIGO detector characterization, machine learning, and citizen science. It was launched on Zooniverse — an online platform for citizen science — on October 12, 2016. In Gravity Spy, citizen scientists sift through the enormous amount of LIGO data, classifying poorly-modeled noise transients known in the LIGO community as glitches. Machine learning algorithms learn from this dataset, sort through more LIGO data, and choose the most interesting and abnormal glitches to send back to the volunteer scientists for further classification and characterization.

As of February 2017, thousands of registered volunteers had made over one million classifications of O1 glitches. Citizen scientists have also discovered multiple new glitch categories through discussions in the Zooniverse forum. Gravity Spy also makes summary pages of the training sets, machine learning classifications, and volunteer classifications, which are available to LIGO collaborators. Data from LIGO's ongoing observing run was recently added to the project, with new glitches added every day as LIGO continues its search for gravitational waves.

Physics and astronomy are often considered abstruse fields, requiring many years of education and specialized training to be able to contribute even at the most basic of levels. However, both these fields have a rich history of contributions from amateur scientists. Michael Faraday, Thomas Edison, Henrietta Leavitt, and countless others made some of the most influential discoveries in physics without formal degrees in the field, and Einstein



Michael Zevin

on behalf of the Gravity Spy collaboration. Michael is a 3rd year PhD student at Northwestern University interested in developing the next generation of citizen science projects and using gravitational wave detections to glean insight into the astrophysics of black hole formation. When out of the office, he plays music around the Windy City in a rock band and an orchestra and attempts to travel to the infinite corners of the globe.

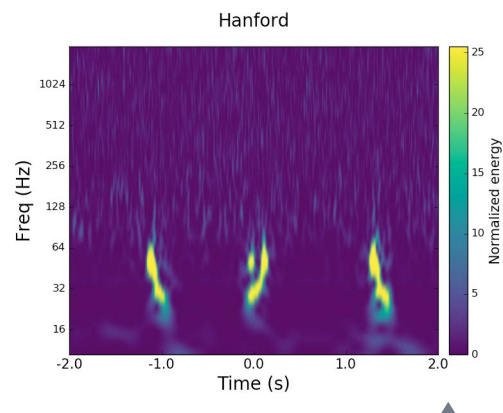
published his four “Miracle Year” papers while working as a patent clerk. As science in general has become more and more specialized, the ability of amateurs to make scientific discoveries of this magnitude is somewhat stifled. However, the public can still play a vital role in scientific advancement due to another aspect of modern science – the exponential growth of data.

Over the past few decades, the volume of data collected by scientific endeavors has made it increasingly difficult for small groups of professional scientists to perform comprehensive analyses. Thankfully, this increase in data collection evolved coincidentally with the internet's universality, providing a means to send data to huge groups of volunteers for crowdsourced analysis.

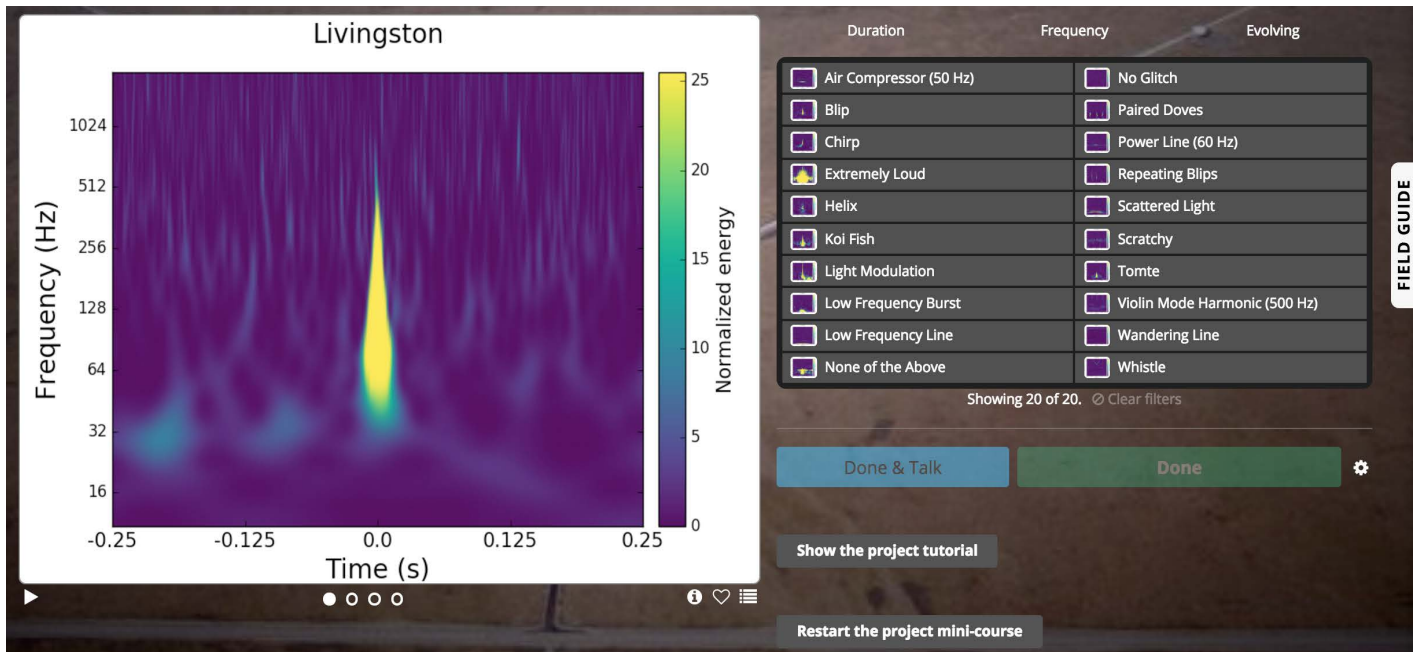
These citizen science projects have proven incredibly productive: millions of engaged volunteers have already led to hundreds of journaled publications over multiple scientific disciplines. LIGO itself has reaped benefits from the crowdsourcing of data analysis since

2005 through Einstein@Home, which provides free software that uses the idle time of volunteers' computers to aid in gravitational-wave data analysis. Gravity Spy is the newest citizen science project to join the ranks, aiming to further expand LIGO's sensitivity to the gravitational-wave universe and develop innovative methods for citizen science in the process.

The extreme sensitivity required to detect gravitational waves is achieved through exquisite isolation of all sensitive components of LIGO from other disturbances. Nonetheless, LIGO is still susceptible to a variety of instrumental and environmental sources of noise that contaminate the data. Of particular concern are glitches, which are transient noise features that come in a wide range of morphologies and can mimic true gravitational-wave signals. Furthermore, new morphologies arise as the detectors evolve. Though some glitches have known causes (e.g. small ground motions, ringing of the



An example of “paired doves”, a new glitch classification made by biotechnology engineer and Gravity Spy volunteer Barbara Téglás. These glitches were later identified by the LIGO detector characterization team as coming from beamsplitter motion (aLIGO LHO Logbook 27138).



test-mass suspension system at resonant frequencies, or fluctuations in the laser), many are still a mystery. All this means that there are loads of glitches in the LIGO data, they turn out to be difficult to comprehensively classify using computer algorithms, and they are detrimental to LIGO’s search for gravitational waves by both limiting the amount of usable data and by increasing the background noise levels in gravitational-wave searches.

Enter Gravity Spy. This citizen science project couples human classification with machine learning models in a symbiotic relationship, paving the way for the next generation of citizen science projects. In the system, volunteers provide large, labeled sets of known glitches to train machine learning algorithms and identify new glitch categories. Machine learning algorithms “learn” from the volunteer classifications, rapidly classify the entire dataset of glitches, and guide how information is provided back to participants. Users that are less experienced are forwarded images that the machine learning has classified more confidently, helping to train newer users while still harnessing their classification power,

while experienced users receive glitches that are difficult to classify and may represent new morphological classes. Finally, Gravity Spy provides a testbed for experiments on socio-computational systems, and has already led to multiple analyses of how volunteer training, project pitch, and user interface can lead to a successful citizen science project.

The project, which launched in October 2016, has already accumulated over a million classifications of glitches from Advanced LIGO’s first observing run, and continues to bring in thousands of classifications per day. In addition to building large, labeled sets of known glitches, a powerful aspect of the project is the Talk forum, in which users and project scientists can discuss new findings and assemble new glitch categories. Multiple new prominent glitch types have been discovered, further building upon our understanding of the complexities that can generate noise in the detectors. New glitches from LIGO’s current observing runs are uploaded daily, putting citizen scientists on the front lines of detector characterization efforts and further disseminating our nascent field to the general public.

Gravity Spy interface. This glitch, called a ‘Blip’, commonly occurs in both detectors, has no known cause, and is one of the most detrimental to LIGO’s sensitivity.

The data challenges faced by LIGO are not unique. The increasingly large datasets that permeate every realm of modern science require new and innovative techniques for analysis. Crowdsourcing has proven effective for data analysis endeavors across multiple scientific disciplines, but the exponential growth of data acquisition necessitates even smarter ways to perform citizen science. The Gravity Spy system aims to accommodate this by providing data tailored for each volunteer based on their experience to expedite the accurate analysis of images. By integrating human and computer classification schemes in this way, citizen science will maintain its role as a prolific scientific tool and scale with the ever-increasing datasets of the future. Utilizing the strengths of both humans and computers, this project will keep LIGO data as clean as possible, and help to unlock more of the gravitational wave universe.

Join the science today at www.gravityspy.org!

Convincing Congress: How initial funding for LIGO was secured

Dr. Walter Massey has held numerous prestigious positions throughout his career. One of them was NSF Director from 1991-1993 when LIGO's funding was approved and the sites were selected. He is currently the Chancellor of the School of the Art Institute of Chicago (SAIC).



A conversation with an early supporter of LIGO, from the days when its future was far from certain. Dr. Walter Massey was a critical component in LIGO's initial funding approval during his tenure at the National Science Foundation (NSF).

Can you share a bit about your background and how you became director of the NSF?

I am a theoretical physicist by training. I was appointed to the National Science Board by President Carter in 1978, while at Brown University, and in 1990 (I was then at the University of Chicago) I was appointed a member of the President's Council of Advisors on Science and Technology (PCAST) by President George H.W. Bush. While on PCAST, I was nominated

by President Bush to be the NSF Director. My name was suggested by the President's Science Advisor, Allan Bromley.

LIGO was the largest investment the NSF ever made at the time, and, according to some, quite risky. There were those that argued the money could be better spent on many smaller and less risky endeavors. Yet, during your tenure, LIGO's initial funding and approval was secured and the two sites were selected. What was it that excited the NSF about this project and how did these processes work? How much involvement did you personally have?

The initial funding for LIGO, in its planning and development stage, had begun before I became NSF Director in 1991. In fact, the process for securing the funding was very long and protracted, beginning around 1980. During my tenure as director we had to take the decision whether or not to make the first very substantial investment in the project, including selecting sites. In a sense, site selection would make the project "real." Inside NSF the project was shepherded and championed by Richard (Rich) Isaacson, among others in the Physics Division, and William (Bill) Harris, Assistant Director for the Mathematics and Physical Sciences Division. There was also competition within NSF from other proposed big projects, especially the Gemini Telescopes and the National Magnet Laboratory at Florida State. Bill and his team had to prepare convincing cases for all three projects for me and the National Science Board. Which they did.

The big hurdle external to the agency was convincing congress to fund LIGO. This was complicated by the public and very vocal opposition to the project by some leaders of the astronomy community. One very prominent member of that community even testified against the project at a congressional committee hearing. The fact that he was also at the time Chairman of an NSF Advisory Committee gave his testimony added weight.

As Director, a large part of my job was spent in cultivating and developing friendly relationships with key congressional leaders. The NSF enjoyed great respect from both Democrats and Republicans at that time. The scientists involved, especially Kip Thorne and Robbie Vogt, also spent a great deal of time meeting with members of Congress and their staffs to explain the project, and getting them excited about its scientific prospects.

Fortunately, we had some very strong supporters of NSF on the hill, in both the House and Senate: Congressman Louis Stokes of Ohio, Senator Barbara Milkuski of Maryland, and especially Senator Bennett Johnston and Congressman Robert Livingston, both of Louisiana, who were critical in marshalling support. Selecting a site in Louisiana certainly was the key factor in their decisions.

However, it was not an easy sell inside or outside NSF. NSF had never made an investment of this size in one project. One of the major selling points, in addition to the science, I suspect, was that if NSF did not support the project it would not be realized. Neither NASA nor DOE, the other builders of big facilities, would have supported the project. And LIGO fit perfectly within the NSF's mission of supporting high-risk, long-range fundamental research. But it was also important to congressional supporters that building and operating LIGO would generate high-quality jobs and hope-

fully technology and educational spin offs wherever it was built. I have always thought that these are legitimate concerns and priorities for elected officials, as long as the science is not compromised in the process.

I feel that LIGO has fulfilled (probably exceeded) the expectations of the science and political communities.

You are a big advocate of outreach and attracting new students to science. What advice would you have for us to attract new students to the LIGO Scientific Collaboration?

The opportunities for the LIGO scientific community to be even more aggressive in outreach to the general public and especially youngsters is greater than ever, given the tremendous excitement and publicity generated by the detection of gravitational waves. I think the LIGO website is already a wonderful resource for these activities. I would also urge (and I know many are doing this) the LIGO scientific, and non-science, staff to personally give presentations to educational, civic, and cultural institutions: schools, Rotary, Kiwanis, Lions Clubs, community centers, etc. I really like the idea of summer internships for high school students, in particular for women and other underrepresented groups in science.

In addition to your various prestigious scientific roles, you were the President and are now

the Chancellor of the School of the Art Institute of Chicago (SAIC). Would you say this role is significantly different from your scientific positions, and if so, what motivated you to get involved in a different field? What aspects of scientific research and discovery can be applied to the artistic process and vice-versa?

I am often asked about my experience being President (and now Chancellor) of the SAIC, and how it differs from being at scientific institutions. Not as much as one might think. Of course the problems and projects students and faculty pursue are different, and their approaches and methodologies differ, but there are also commonalities which in some ways outweigh the differences: the curiosity, creativity, dedication, passion, and the drive to explore beyond established boundaries are very similar. So in many ways I have felt very much at home.

At SAIC, we have initiated a number of programs and efforts aimed at exploring and discovering overlaps, connections, and mutually enhancing intersections between art and science, such as a Scientist-in-Residence, Conversations on Art and Science, and jointly taught courses by artists and scientists. We are also collaborating with scientists and engineers at the University of Chicago, Northwestern and Argonne National Laboratory to further enhance these efforts.

LIGO₂₀₁₇

Western leg of LIGO interferometer on Hanford Reservation.



LISA Pathfinder & LISA in brief

Next steps towards a gravitational-wave observatory in space: L3 Proposal submitted in January 2017.

In response to the call of the European Space Agency (ESA) for L3 mission concepts, the LISA Mission consortium submitted the proposal for the Laser Interferometer Space Antenna (LISA) on 13th January 2017. The full LISA Proposal can be downloaded from the consortium website: https://www.elisascience.org/files/publications/LISA_L3_20170120.pdf

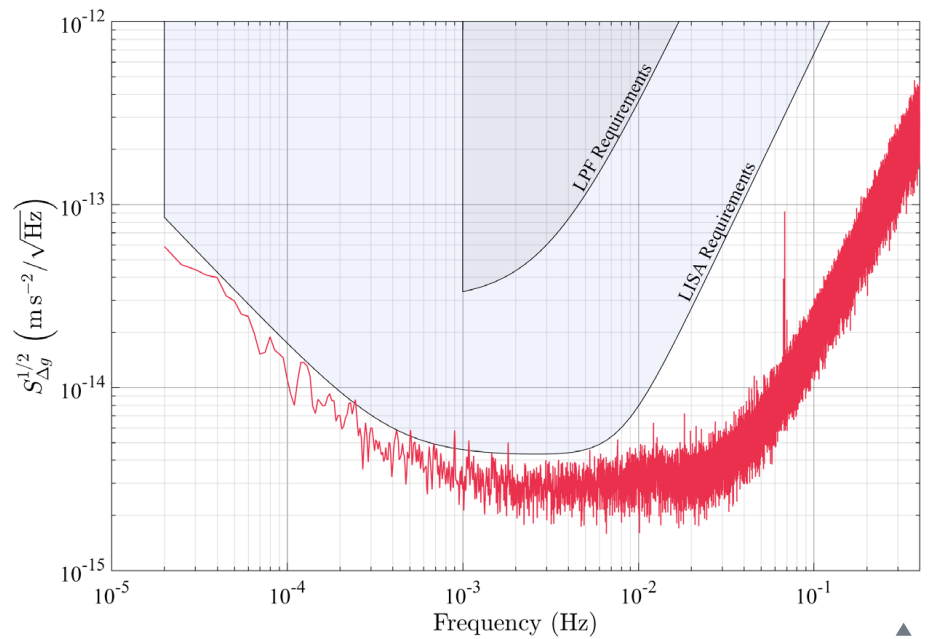
LISA Pathfinder's pioneering mission continues and gets a six-month extension

On 7 December 2016, LISA Pathfinder started the extended phase of its mission, an additional six months during which scientists and engineers will push the experiment to its limits in preparation for ESA's future space observatory for gravitational waves.

During the extended mission of LISA Pathfinder, the team will run a series of long-duration experiments to better characterise the mission performance especially at the lowest frequencies that will be probed by the future observatory.

LISA Pathfinder Science Archive online

ESA's LISA Pathfinder Science Archive has opened its virtual gates to the world. It contains data collected by the satellite during the mission's first few months, covering the nominal operations phase of the LISA Technology Package (LTP) – the European payload on LISA



Average differential acceleration noise measured by LISA Pathfinder shows that the mission has surpassed its original requirements, reaching a level of precision better than that required by a future gravitational-wave observatory.

Pathfinder. The LISA Pathfinder Science Archive is hosted at <http://lpf.esac.esa.int/lpfsa/>

NASA microthrusters achieve success on ESA's LISA Pathfinder

The Space Technology 7 Disturbance Reduction System (ST7-DRS) is a system of thrusters, advanced avionics and software managed by NASA's Jet Propulsion Laboratory in Pasadena, California. As of October 17, the system had logged roughly 1,400 hours of in-flight operations and met 100 percent of its mission goals.

Most thrusters are designed to move a spacecraft, but ST7-DRS has a different purpose: to hold Pathfinder as perfectly still as possible. This allows the spacecraft to test technologies used in the detection of gravitational waves, whose effects are so minuscule that it requires extreme steadiness to detect them.

Balancing all the disturbances on the spacecraft allows Pathfinder's instruments to stay in near-perfect free fall. This lays the groundwork for a future gravitational-wave observatory in space, which will need this kind of stability to cancel out any force other than the subtle tug of gravitational waves produced by massive objects like black holes.

"This achievement represents the last hurdle for this microthruster technology development, which the project has been chartered to perform", said JPL's Phil Barela, project manager for ST7-DRS.

U.S. National Academies Report recommends NASA to restore support for LISA

Following the LIGO results, the New Worlds, New Horizons: Midterm Assessment of the Astrophysics Decadal Survey report recommended that NASA restore support this decade for space-based gravitational wave research so that the U.S. is in a position to be a strong technical and scientific partner in a planned ESA-led gravitational-wave observatory. The report notes that U.S. participation could enable the full scientific capability for the ESA-led mission as envisioned by New Worlds, New Horizons.

ESA's Gravitational Observatory Advisory Team

also completed a report in 2016 recommending that ESA pursue a spaceborne gravitational-wave observatory, after LISA Pathfinder verified the feasibility of a multi-satellite design with free-falling test masses linked over millions of kilometres by lasers.

How to get a faculty position?



Conor Mow-Lowry

is a Lecturer of Astrophysics at the University of Birmingham. His hobbies include extreme sarcasm, moving to places with increasingly poor weather, and embarrassing himself in a loud voice.



The Aston Webb buildings, Chancellor's Court, at the University of Birmingham.

My glib answer to this question is: try being lucky. I often feel that is what happened for me. Somehow I was in the right place at the right time, the stars aligned, some people got sick and others changed their minds, and I ended up as an academic staff member at the University of Birmingham.

Perhaps that's what happened, but for the purposes of this article, let's pretend that some decisions I made (consciously or unconsciously) helped.

Some things definitely help. Be willing to travel for a job, especially for a post-doctoral stint, and preferably work on something that gives you a chance to learn some complementary skills. Have an open mind, and don't artificially narrow your options. Talk to people and really listen to their answers – feigning understanding doesn't impress anybody, and it eliminates important chances to learn or collaborate.

I shudder to say the word, but networking is obviously important. I prefer to use

terms like 'talking to people', or 'being social'. Chasing someone down after an interesting presentation and discussing their work, asking for advice from somebody working on a related experiment, or offering some help where it seems like you can contribute – all of these things get you known, and they're also usually informative and fun. After all, you won't be offered a job if people don't know who you are. (Some people might describe this as "being loud and annoying", "making people feel important", or "sticking your nose where it doesn't belong" – but hey, how many academics do you know that are shrinking violets?)

In hindsight I think there's a point I underestimated: have fun! If you enjoy science, and you're fun to work with, people will want you around. It will make you interested in starting more collaborations, learning the answers to more questions, and keep you pondering while you're on the bus or at lunch or in the shower. It's what

drives me to put in an extra hour – I've done my mandatory work for the day, but there's that little simulation to write, that mechanical part to draft (I like CADing), or some new data to record.

Finally, don't waste opportunities! If somebody asks you whether you're interested, say yes! If they ask you to apply, do it even if you don't know whether you want the job! Make that call back, travel when invited, listen to advice (even if you ignore it later). I hadn't seriously thought I would find a position when I did, but when the opportunity came I made sure not to let it slide quietly by.

Now that I have a faculty job, I find that the demands are many and varied and often not very science-based. This makes having fun considerably harder (for now at least), but that would be the topic of another article: "Do you even want a faculty position?"





'Infinite LIGO Dreams' by Penelope Rose Cowley
The artwork is on permanent display in Cardiff Physics Department's 'Rest Frame' room to celebrate the discovery of gravitational waves.

www.peneloperosecowley.com

Kai Staats

To catch a Wave: A detection story

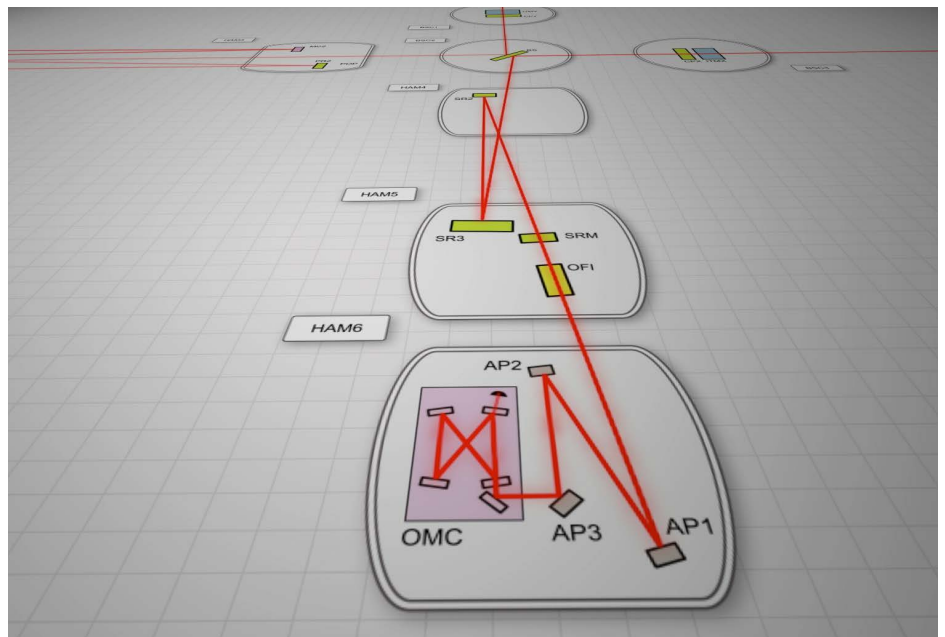


is a filmmaker, writer, and aspiring researcher who in 2016 earned his MSc in Applied Mathematics at the Square Kilometre Array in South Africa. He has completed three films for LIGO and is now working with Marco Cavaglia and Michele Zanolin on the application of genetic programming to LIGO data for glitch classification and supernovae detection, respectively.

On September 14, 2015, a day in which all of the LIGO Scientific Collaboration members received notification of a most important possibility, a day that would lead to the validation of the final piece of Einstein's theory of general relativity, a day which opened a new era of astronomy – on that historic, auspicious day, I was completely, totally, utterly... unaware.

At that time I was living in South Africa where I was working toward my MSc at the Square Kilometre Array. On September 14, I had completed the final segment of a test suite that marked the transition from code development into data runs. When, five weeks later, Marco Cavaglia alerted me to the detection event, delayed as my reaction may have been, I broke into a cold sweat and immediately set about pacing the length of my apartment for the better part of the afternoon. I felt completely isolated with this news, for I could tell no one, talk about it with no one. As a filmmaker, I was thrilled to be given this opportunity, to be one of a thousand people in-the-know. At the same time I was horrified that nearly six weeks had been lost which were critical to capturing the story for a new, totally unexpected (and not-yet-funded) film.

My first thought? My research can wait. I'll put my degree on hold! I'll ask for an extension into 2016 in order to capture the next few months on film. I researched tickets back to the U.S. and the cost of renting or buying a camera, as I had sold mine to pay for the final nine months of living in South Africa. I called



▲ *Top: Calum Torrie testing a prototype of a vibration dampener.*

Bottom: A rapid exploration of the inner workings of the laser interferometer I.

Marco to tell him my plan. He talked me out of it, saying the entire organization was deep in data analysis, engrossed in computer screens and a continuous stream of conference calls. So, I did the next best thing. I drop-shipped six cameras from Amazon to the Hanford and Livingston observatories, Caltech and MIT. From my apartment in South Africa I uploaded a quick instructional video and requested that the recipients of the cameras capture a video diary, a recording of conference calls, working in the labs, evaluating calculations, even thoughts while commuting to and from work. Marco Cavaglia, Dale Ingram, Mike Landry, and Betsy Weaver rose to the challenge, capturing many hours of footage.

In all three of my films for LIGO, I employ musical interludes to grant the audience time to process what has been learned. For LIGO Detection I compiled video diaries (coupled with some of my own footage) as a time lapse set to a musical score. This interlude captures much of the LIGO experience: experimenting with physical mock-ups; fixing things that broke; commuting and telecommuting for meetings, meetings, and more meetings; finding balance between work and play; learning from each other as professors, students, and colleagues; and yes, maintaining a wonderful sense of humour.

Upon returning to the States on December 1, 2015, I immediately booked a flight to MIT in order to conduct more formal interviews. Once on campus, I was welcomed by a palpable energy, enthusiasm that worked to counter the daunting task of all that had to be prepared for the pending paper and eventual media event.

It was then that I realized I had not missed the story, for the story was yet unfolding. The collaboration was moving from proving to themselves the event was real, to demonstrating to the world their due diligence in that validation process. The paper was being written. The escalating rumours were being managed.

The final, important details of the data analyses were being vetted.

Of arm waving and animating

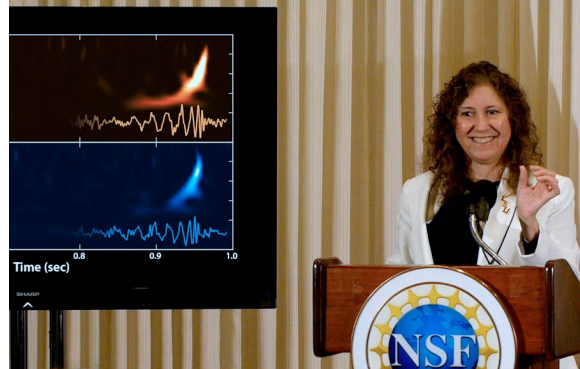
Humans are incredibly adept at sharing complex subjects. Not with the use of our voices alone, but with fingers pointing, interweaving, and taking on the form of whatever it is we describe. In combination with our arms, those many degrees of freedom left and right give us an uncanny ability to convey a lifetime of stories, from the simple telling of a joke, to the propagation of waves across the arms of an interferometer.

As a filmmaker, I never desire to replace what we do so well. Rather, I augment our natural propensity for knowledge-sharing through a light treatment of computer-generated art and animation.

In my first two films, I added sketches to support the fantastic claims proposed by Mike Landry. My visual FX artist Leonardo Buono and I brought to life the stories told by Jamie Rollins and Gaby Gonzalez. With Rai Weiss I drew sketches in parallel to his blackboard presentation in order that the audience could more fully appreciate the trap laid to catch a passing wave.

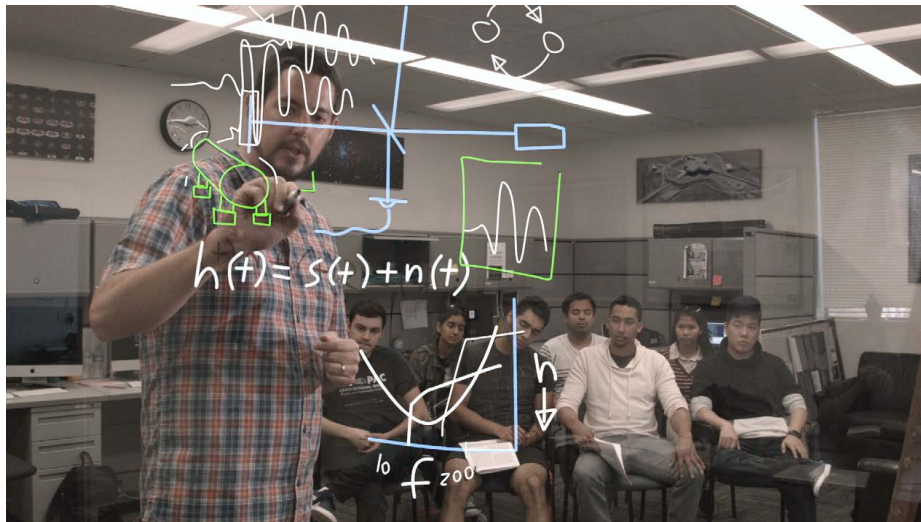
While a good trilogy should allow for each film to stand alone, it is important not to tell the same story three times. Validation was central to the theme of LIGO Detection, and central to validation is discerning signal from noise. Often difficult to describe without discussion of complex waveforms and massive datasets, I saw an opportunity to explain glitch isolation in a classroom setting.

As the LIGO Scientific Collaboration is composed of professors and their students, the next generation to learn about and some day, perhaps, work in gravitational wave astronomy, I asked Josh Smith, Geoffrey Lovelace, and Jocelyn Read if I could visit California State University Fullerton in mid-June.



▲
 Top: Lisa Barsotti sharing how she was awoken by news of the detection, and proceeded to “hit on her husband” to get up!
 2nd: Gabriela Gonzalez presenting at the Media Event in Washington, D.C. on February 11, 2016. 3rd: Stanley Whitcomb explaining the validation process. Bottom: Rainer Weiss sharing how he was alerted to the news of September 14, 2015.

Of Arm Waving and Animating



Joshua Smith talking to undergraduate researchers about glitches.

Upon arrival, I immediately noted the completely open classroom, a single environment which served as a lab, workshop, and study hall combined. Personal workstations juxtaposed to couches and a conference table slash guest workspace made clear this was a place of interactive learning... and perfectly suited for a documentary film.

I ordered a massive sheet of tempered glass and transported it to Fullerton from Pasadena in the back of my Subaru with fractions of an inch to spare. With the assistance of Josh's students, we carried the glass to the lab and propped it on the backs of two chairs. A janitor's wooden ladder, two spring clips and tape, and we had constructed a simple, yet effective transparent blackboard. If my film were not limited to 20 minutes, I would have gladly shared the entire session of engaging questions and answers. Later, my VFX artist Leo brought Josh's explanations to life through color and animation, every segment of each figure assigned a vector.

The voices of LIGO

One of my principal goals with LIGO Detection was to make it clear that LIGO's success was built upon an international effort. Yet, I did not have the funds to travel to each and

every country in which a LIGO Scientific Collaboration member conducted research. Marco, Leo, and I discussed how best to capture the global engagement, and the idea of voices mapped to a spinning globe was born (Marco claims it was his idea, but Leo and I recall otherwise).

In late August, Marco and I reached out to more than 100 LSC members with the request that they record a story of what they were doing and how they felt when they first learned of the potential detection on September 14, 2015. Many of those voices open the film against a beautiful 3D model of the Earth hand-crafted by Leo. For me, this is the most haunting part of the film, for it brings the audience into the moment, as though it were happening all over again.

A passion for storytelling

Filmmakers hope to come away from each hour of an interview with just a few minutes of solid, usable material. If all goes well, these guided conversations yield powerful moments in storytelling but seldom a contiguous story for the retelling. In the interviews I conducted at MIT, at the semi-annual conference in Pasadena, Caltech, Fullerton, and Embry-Riddle, I was spellbound by the depth

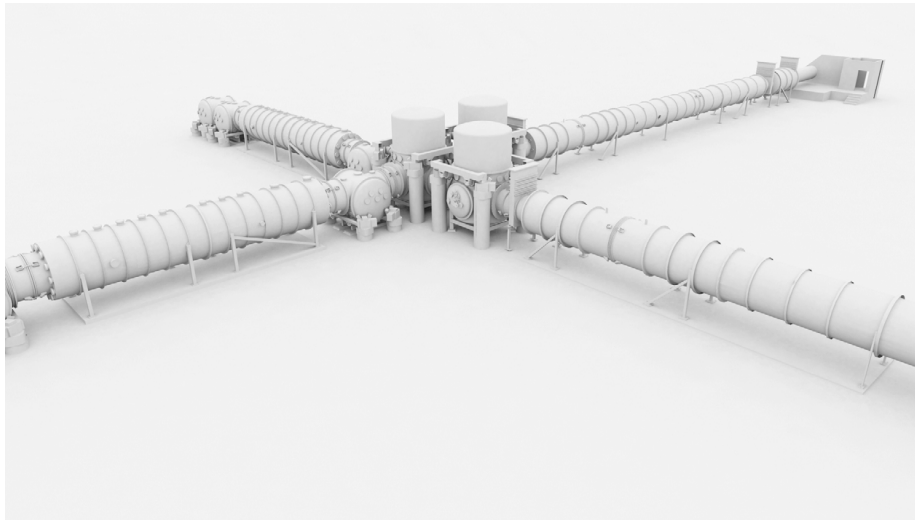
of passion married to the breadth of information shared. I now have in my archives ample material for a feature length film which could, with a relatively light treatment of animation, capture the attention of the scientifically minded audience for hours on end.

As a new member of the LSC, I joined the GW150914 and EPO (Education and Public Outreach) mailing lists in early January 2016. I learned a great deal through the daily reading of those exchanges. I gained a layman's understanding of the function of the interferometers, of the dynamic nature of the sources of gravitational waves, and perhaps most important of all (from my point of view), I learned how LIGO scientists love to share their knowledge and passion for how the universe is formed.

This flies in the face of the dominant stereotype of the men and women of science. Hollywood, perhaps more than any entity, is guilty of wrapping super geek personalities around super smart characters who fail to communicate anything but unintelligible geek-speak. While I cannot make a claim for all branches of science, it seems that stereotype is outdated, or perhaps was never true.

My director of photography and I were granted the opportunity to attend the February 11 Media Event in D.C. – a true honor which I will not readily forget. As my experience behind the camera is focused on the interaction with the person being interviewed, it is only when I review the footage that I learn what I have captured. In the edit of this film, I was reminded how members of this collaboration enjoy sharing and teaching.

Dave Reitze, Gaby, Rai, and Kip could have stood before the world and gone on about the challenges, the hurdles, the great foundation laid for future astronomers. They could have bragged about what they as individuals have accomplished. But they didn't. They spent



▲
A rapid exploration of the inner workings of the laser interferometer II.

their time in that limelight, each of them, explaining how those who came before them, how the entire collaboration, made the detection possible. They used the majority of their time to explain a portion of Einstein's theory of general relativity in a way that everyone watching, the reporters in that immediate audience and the millions at home, even the U.S. congressmen, could understand. It was not dumbed down. It was not a pedantic chore but a joyful telling of the story of gravitational waves from generation to transmission, from detection to validation.

I am almost embarrassed to say how much fun this brings to my work. I don't have to drag a tortuous convolution of archaic phrases from the mouths of reluctant textbook academics. No! I need only reduce fluid stories from their full telling to a more concise digestion, sometimes augmenting with animation or a musical score. Then my audience too enjoys the stories as they are told by some three dozen LIGO researchers over three and a half years. Everyone I have worked with in the LIGO Scientific Collaboration has been generous with his/her time, eager to explain the theory, the instruments, and the detection in a way that is enjoyable on screen.

Why does this matter?

When someone asks how something functions, no matter whether it is the inner workings of cellular biology or the outward propagation of gravitational waves from two merging black holes, and the answer given is understood, something inside that learner comes to life – especially in young learners who are so wonderfully eager to absorb. You can see it in their eyes, in the transition of their posture from hesitation to overt "Wow! I get it!" In those moments of "Ah-hah!" both the giver and the receiver share in the pleasure of discovery.

No, we cannot expect everyone who learns of the detection of distant, formerly unseen phenomena to become excited, to ask to learn more. Some will always shrug their shoulders and walk away. Some will complain, as with the cost of placing boots on Mars, that we have problems right here on Earth that need to be addressed before we dedicate taxpayer money to observing distant galaxies. But if the effort of the EPO group, if the enthusiasm of the professors in the collaboration, ignite just a few imaginations each semester, and a few of those students go on to a career that opens new doors to our understanding of the

universe, then we will have succeeded in our work in outreach and education.

That is my hope for these films: that somehow I have touched the imagination of just a few individuals with each showing.

Confessions of a filmmaker

In my former life as CEO of a Linux software development firm, I spent many months of each of those ten years on the road at the Department of Energy, NASA, and university labs, helping my clients design supercomputing clusters that met their needs. But each time I shook hands and drove away, I was torn, for part of me desired to stay.

With the sale of my company and a few years later my diving into a masters degree, I worked to fulfill my dream of returning to the sciences not as a salesperson, but as someone contributing to the scientific community. My camera and passion for storytelling through film is part of that journey. Now, I am also working with Marco Cavaglia at the University of Mississippi and Michele Zanolin at Embry-Riddle on the application of evolutionary computation (a kind of machine learning) to LIGO data for the classification of glitches and the separation of noise triggers from candidate supernovae, respectively. In this dual role of filmmaker/budding researcher I feel incredibly fortunate to have come on board at this time in the four decade history of LIGO.

Thank you. And I look forward to what is to come...

LIGO₂₀₁₇

*The third in the series by filmmaker Kai Staats was launched in February by New Scientist and can be viewed here: <https://www.newscientist.com/ligodetection>. The first two films, *LIGO: A Passion for Understanding* and *LIGO: Generations*, can be viewed here: <http://www.kaistaats.com/film/ligo-passion/> and <http://www.kaistaats.com/film/ligo-generations/>.*

Job Hunting beyond Academia

The past two years at Apple have been a great experience for me, very different from my previous academic life. I still work on R&D but the way work is structured is quite different. Projects are typically well defined and deliverables constantly kept in sight.

That doesn't happen naturally – very powerful and unforgiving feedback forces exist to ensure that work stays on track. Like in academia, timelines can still span over many years and some projects can definitely be very exploratory and ambitious, but the path is typically structured and broken into incremental steps in a way that makes them appear more within reach. **Breaking a big problem into small bits and being able to measure daily progress towards a particular goal can be extremely motivating and rewarding.** It is a remarkable source of productivity and creativity that unfortunately is not always fully tapped in academia.

It all started by chance, in the sense that I was recruited through LinkedIn, thanks apparently to some key words in my profile. LinkedIn is definitely the first resource companies use, although they know that it's often a low SNR repository. Probably the best doors to any job are connections. Referrals, especially if given by someone with a close link to the job opening, present companies with an attractive shortcut for filling positions.

As LIGO researchers, we have a highly valuable background to bring to the table. Not only are we knowledgeable about many topics (optics, lasers, controls, electronics, data analysis, modeling, etc.) but we also have a

rigorous mindset that comes from learning for decades how every factor, even the smallest, matters.



Alberto Stochino is currently a Technology Development Engineer at Apple in Cupertino, CA. He worked on LIGO from 2005 to 2012 as an undergraduate through to a postdoc in Italy, Australia and the US. He loves road and mountain biking and has very fond memories of racing along the Y arm at Hanford.

Why seek a position outside of academia? There are many reasons. **Timing, opportunity, culture, funding, family, and more. For me, it was mainly two reasons. First, the well-known two-body problem. Second, the indeterminacy and often fierce competition of the academic career path left me seeking a different route.**

There is, of course, no one recipe for landing a position outside of academia. There are, however, a few things that will help. **First, the standard pieces: preparedness, patience, persistence, and of course a bit of luck. Hint: you can make a little of your own luck.** Now for the other pieces.

Make a mental model of potential employers. I focused my resumé, 2 pages, on the traits that I imagined they'd think important. Later I learned how important it is to really make these crystal clear, even if it made me uncomfortable in the beginning. Support your

strengths, or just show them, with results, project deliverables, decisions, any evidence of impact.

There are challenges in being a physicist looking for non-academic positions. Some potential employers have never spoken to a physicist before, ever. They do not know what physicists do or are capable of doing, and the generality of a physicist's skill set will often be surprising to them. It doesn't help that we usually don't know the standard business or engineering language. A lack of "industry experience" is another challenge. This comes down to understanding schedule-driven speed of delivery, the simultaneous pursuit of multiple projects, managing a different kind of bureaucracy (but still a bureaucracy), and realizing that independent discovery of the general solution to a problem is not strictly required.

Along with the acquisition of a non-academic position came the realization that I no longer pursue fundamental research. This can be a lengthy acceptance. The consolation, if you have found a fertile project or company, is a wealth of opportunity, a richness of self-determinacy, and the many, many scientific and engineering challenges that exist alongside and between the fundamental results that your academic colleagues continued to pursue.



Justin Garofoli was an operator at LIGO-WA from 2002 to 2008. He completed his PhD at Syracuse University in 2014 with research in particle physics, including spending a couple of years at CERN. After a brief period at SLAC, he now contributes to Project Loon at Google X.

In order to leave academia for industry, you'll need impetus and self-knowledge.

The impetus can come from a change in your circumstances and priorities as much as it may come from a shift in research funding. You will need something to give you a push, because change is scary and the potential well you need to escape is deep. It's better to start working out what your professional options are significantly in advance of needing to put your plan into action.

For me, the impetus to take my first job in industry came when I moved in with my partner who was starting a postdoc at NIKHEF. I joined the next-generation photolithography system development team at ASML as a thermo-optical designer. Working at ASML felt quite similar to the LSC: a huge number of engineers and physicists engaged in getting a large number of photons exactly where they want them and achieving this by making technological developments on all fronts. As a first step out of academia, it was a refreshing new challenge and a whole new way of working.

Once you've got the impetus, there's the self knowledge. Unless you're leaving to work for your own company, it's highly unlikely that you'll be working in your actual speciality. Think more about what you actually do all day and look for something that allows you to use those skills. Do not underestimate your expertise. I didn't think of myself as a person who could write code during my academic career, but coming into industry I realized that I could hack a program together efficiently enough to get the job done.

It's also worth considering what type of company culture and atmosphere you might thrive in. A huge multinational technology company has a different vibe than a small startup. When you're attending interviews, pay attention to your surroundings and try to work out whether they have that intangible sense of a happy and productive workplace.

I'm having a great time working in industry.

Each new role I've taken on has offered me the chance to widen my experience and continue my passion for learning, and has created a great platform for an interesting and fulfilling career.



Eleanor Chalkley is currently an instrumentation design physicist at Land Instruments International. She completed a PhD in the Institute for Gravitational Research at Glasgow University in 2009. She also writes extensively on European pop music.

I hadn't considered a career in data science as a physics graduate student. For my PhD, I worked on tests of the no-hair theorem of BHs and the Dark Matter distribution at the Galactic center, and did very little computer programming. My research was based on analytical calculations, and the only computational tools I used were Maple and Mathematica. Eventually I used C to carry out some numerical integrations. That is how little I was exposed to programming!

It was my postdoc in LIGO that introduced me to data analysis. I was very new to working with data or using a computer cluster for research. Coming from the analytical world of GR, I had a very steep learning curve before acquiring the mindset of a data scientist. But soon I found out that I enjoyed it, and I realized the power of data and data science.

I have a simple guideline for my life: I always choose the path that excites me the most. Doing research as a graduate student, analyzing data and being a LIGO member were so exciting for me. As I approached the end of my postdoc, I realized I was not that excited about being a faculty member. However, I still wanted to do research and use the power of data science in the modern sense. I really

liked how companies are working on very practical topics at a very fast pace, and was also delighted by the wide spectrum of roles available at these companies (from software developers to managers) and the culture seemed like a good fit for me.

I applied to the Insight program, an intensive, 7-week postdoctoral training fellowship that bridges the gap between academia and data science. It's a very competitive fellowship, and I was accepted into the Silicon Valley program after applying twice. Afterwards I interviewed at various big companies and finally accepted an offer as a data scientist in Facebook's Analytics team. I just recently started, and I am looking forward to this new chapter in my life.



Laleh Sadeghian got her PhD at Washington University in St. Louis. After working on low-latency LIGO data analysis using `gstlal` for more than 3 years as a postdoc at UWM, she just started a new chapter of her life as a data scientist at Facebook in Silicon Valley.

I have worked for more than a decade on gravitational-wave detectors – starting in Virgo and spending most of my academic life at LISA Pathfinder in Trento and then Advanced LIGO in Birmingham – before moving to industry in 2013. Back then I was looking for a better challenge and more stability than another postdoc round, and the right opportunity came from the R&D department of “a Dutch company, leader in the semiconductor industry”. From initial curiosity, as their recruiters actually “headhunted” me, to the excitement of a role at the forefront of a leading technology, soon the offer I was made was too good to be refused.

Looking back, I don't think there's a simple

rule of how to get a position in industry coming from academia. Companies driven by innovation value very much research background. Large ones often just search for smart people who demonstrate the ability to learn fast and work independently, as they have means and resources to train you on the specifics of the role. Technical skills may be critical in smaller companies where, due to budget, a strong match with the required profile is sometimes preferred. Being familiar with collaboration work, planning and deliverables (like in Advanced LIGO) is an advantage, and, I must admit, the range of expertise developed as a GW experimentalist helped in my case. Nevertheless, finding a job in industry isn't easy and requires certain open-mindedness; beware that your CV is reviewed from a different perspective and that during the interview mindset and language may differ from what you are used to. It also requires some luck. I know brilliant scientists who have never even managed to get to the interview stage.

In my experience, industry is not a 9-to-5 job as some may naively think. **Passion and commitment are still key, and just like in academia, you must prove yourself in different areas to build a career.** I appreciate the diffuse culture for prioritization and pragmatism, efficiency and simplification (which doesn't mean doing things superficially), and I like how creative ideas and problem-solving are generally encouraged. I found these were often left for self-learning in academia, and don't always come out as straightforward. Colleagues are very knowledgeable and competent, and as a physicist you still do physics on a daily basis. From academia one may probably miss teaching and some freedom to try out crazy ideas, particularly in the lab. The payback is little administration or writing proposals. Overall, the real difference is the approach to the two jobs: in research you can push the limits as often it is sufficient to make your experiment

to work once to prove your idea. In industry you want to deliver a product and this does not work if it fails even once, so you must be careful taking risks.

Overall, I regard industry as a positive experience to broaden your views and learn a lot, and I definitely recommend it.



Ludovico Carbone is a senior physics development engineer at ASML, developing new sensors for next generation lithography machines. He likes to deal with noise in physics and in music. His passions are history, food, travelling, and a football team wearing a black-n-white jersey, but most of all he loves his time with his son Luciano.

A PhD in physics opens candidates to a wide range of possible job roles in the technology industry. In Silicon Valley, it's quite common to find software engineers who studied physics. In addition, LVC members may explore opportunities as hardware engineers or quantitative analysts. For those with a good mix of leadership, organization, and technical skills, a role as a technical program manager may be a good fit.

Speak to people you know who work at companies you are interested in. Ask if they know of opportunities, and if they do, how to best send a resume. An internal submission may have a better chance at success than a post through the company's jobs website. Though an imperfect tool, a profile on LinkedIn can help you connect with recruiters.

I suggest a resume limit of 2 pages, including contact information, previous experience, education, and a list of technical skills. The latter will be scanned, either by eye or by machine, for matches with the qualifications listed on

the job posting. Shorten your publication list to your greatest hits, with a link pointing to the full list. The experience section should include a list of your previous roles and accomplishments. Focus on the changes you made while in the role and the impact they had, not simply your responsibilities.

The whole interview process may progress through multiple stages of phone and in-person interviews, and can take weeks to months. It's good to explore several opportunities in parallel, for which you may want to use a spreadsheet to keep track of contacts and important dates. Don't be afraid to do some light nagging to keep things moving along. An in-person interview at some technology companies can be very similar to an oral exam, and you should prepare for it as such. You will be given technical problems, be asked to walk through problem solving, and also be tested on your domain knowledge relevant to the role, as well as on your previous experience.

At the end of the day, finding the right job is partly a matter of luck. So do your best, don't stress and good luck!



Nicolas Smith did doctorate and post-doctorate research for the LIGO Laboratory and currently works as an imaging scientist at Terra Bella, an imaging satellite company which was recently acquired by Planet in San Francisco.

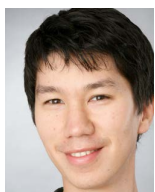
When I received my PhD in 2010, I decided to pursue an academic career, mainly because I really enjoyed doing research, and the field of gravitational wave detectors was very inspiring. In summer 2012, while a postdoc at MIT LIGO Lab, I began to prepare my next move. By then I had

realized more and more that an academic career is characterized by a high degree of uncertainty until getting offered one of the very few worldwide existing professorships. This led me to reconsider my decision on a career in academia or industry.

Reevaluating the professional and personal arguments, balancing them and making a decision was tough and took me a while. In the end I decided against academia since the associated risk was too high and I was interested in learning something new. In addition I felt being biased towards academia because I did not have any experience in industry.

Finding a position in industry was actually much easier (maybe by chance) than making the decision for industry itself. I searched for large companies and positions and had submitted two applications when ASML invited me for a job interview, first by telephone and then on location in the Netherlands. Everything went quite fast, from applications in November 2012, job interview in December, to moving and starting at ASML in March 2013.

Looking back, I have no regrets about my decision and enjoy working at ASML. The working environment is more complex and challenging. **I have learned a lot in the last couple of years, which feels very satisfying.** When I made my decision for industry I was not really aware of two arguments, which became important for me and are confirming my decision: industry (or at least ASML) has more opportunities for personal development and I find it more important to work on products which have a more direct and immediate impact on people's lives than in fundamental research.



Patrick Kwee obtained his doctorate at the AEI Hannover on laser stabilization for Advanced LIGO in 2010. He worked as a postdoc at MIT

LIGO Lab on filter cavities before taking a position in industry at ASML, where he deals with next-generation lithography tools.

After I graduated from Caltech in January '16, I had been looking at careers in various industries, and still had no good answer to the question I kept running into: **What do you WANT to do? Like many experimental physicists, successes during my grad school career were predicated on an ability to draw from many different fields of engineering and bits of math/signal processing/statistics – I learned whatever I needed to in order to build an experimental setup and understand why it did what it did, and I liked it all! I tried to convey what I viewed as a strength to the people I was talking to in industry: "I'm interested in lots of subjects!" "I could find my happiness doing many of the things that I did for my PhD!" "I learn really quickly, I promise!" and many other attempts at communicating my willingness to try new things and desire to explore new rabbit holes.**

After a number of interviews, some offers for things I was objectively unqualified for, some rejections from things I was objectively strongly qualified for, and a lot of post-mortem pondering, a pattern emerged. I had plenty of enthusiasm for solving problems in general, but came across as willing to solve problems for money rather than as excited about any company's particular problem space.

This unfocused job-seeker is not the version of me that industry wants to hire; I needed to be excited about their problem. All of a sudden, it became much easier to figure out which jobs I should apply to: if I could sell it to my own brain as really interesting and started wanting to ask interested questions, then I could sell myself to the company as the asset that they want. Conversely, when I couldn't

hype myself up for a job, it was immediately clear that I shouldn't be applying there.

I would say to my younger self beginning his job hunt: "Stop reading about personal branding. Stop trying to guess job titles to figure out which hole to shove yourself into. Network more than you ever thought you need to, for the meritocratic system is inefficient at matching people with opportunities. **Above all else, follow your excitement and make sure it shows - it foreshadows your best work, and others can see this.**



David Yeaton-Massey got his PhD at Caltech in 2016 working on cryogenic silicon cavities under Rana Adhikari, and now works for Northrop

Grumman doing basic research on single photon emitters in the Quantum Sensing & Metrology group. While not in lab or networking over drinks, he practices Brazilian Jiu Jitsu.

LIGO₂₀₁₇

A Tale from Hanford



Brynley Pearlstone

is a PhD student, studying at the University of Glasgow. In his downtime he likes to play board games and listen to podcasts.

When I started my PhD, my supervisor suggested that there was a chance to travel all the way to America through the LSC Fellow Program, in order to go and work at one of the newly installed Advanced LIGO labs. Of course, I almost bit his hand off. Fast forward a few years, and I'm at the airport in Glasgow with my bags, ready to endure 4 months half-way around the world. I didn't know anybody at the Hanford site, I couldn't drive myself back to the apartments, and I only had \$100 on me.

I quickly settled in at the fellows' apartments. For the first few weeks, I was consistently amazed at what living in the States had to offer. The air of the desert was warm and dry, the flat landscapes meant that you could see for miles, and the locals in town were very friendly, always happy to chat. On one of my first days, I got a little lost walking back to the apartments with bags full of groceries, when a woman at the bus stop told me that I was heading the wrong way, paid my bus fare, then got the entire bus into a conversation about what's good to do in town.

The other fellows were great too. We would share rides into and out of work each day.



▲ *The railway tracks that run beside the highway. The morning train makes an effective alarm clock.*

We would chat all evening, play board games a few nights a week, and of course we would work together too. My main goal whilst out on site was to investigate combs – sets of narrow lines in the spectrum of the detector, regularly spaced in frequency. They had been a big source of noise in the first observing run, and were really troublesome for continuous-wave and stochastic searches. We started by poring over the data from the first observing run, looking at every magnetometer channel and at the combs in the strain spectrum to see if we could find any clues at all. We found that the best coherence with the comb with 0.5 Hz spacing came from magnetometers that were placed next to the electronics racks. Our next step was to spend long days in the electronics bays assessing magnetometers.

But not every day would be spent like that. In February, Jenne Driggers and Jeff Kissel took a few of the fellows, myself included, for a day trip to Seattle. Jenne had been invited to talk about Advanced LIGO at her alma mater, the University of Washing-

ton. The day trip began and ended with a four-hour drive across the state, along the Columbia river, and through the Cascade mountains. Once in Seattle, we met with the researchers there who perform their own experiments to test gravity. A few months later, the same faces came back to the site at Hanford to install a tilt sensor that they had developed, and they stayed on site for a few weeks to set it up and make sure all was well. People coming and going at the site are a common occurrence, some more regularly than others. One or two guests would spend a week at the site each month, when not away on the East Coast.

Even outside of work, the fellows often operated together, whether it was all going to see the new Batman vs. Superman movie (bad), meals out to the local Mexican restaurant (good), or much grander trips. On a number of occasions, we would go away together on overnight trips, to explore the Pacific Northwest. One weekend, four other Fellows and I booked Airbnbs and took a weekend trip down to Portland. Another week it was a weekend in Seattle. Day trips

What I think about when I think about gravitational waves

Ananda Lima

holds an MA in Linguistics from UCLA and has taught at UCLA and Montclair State University. She is currently working on a poetry collection and a novel. Her work has appeared in The American Poetry Review and The Offing.



were not out of the question either, with Walla Walla less than an hour away, offering lots of wine tasting. It wasn't only the fellows who were accommodating and inviting. Hiking and board gaming were key activities for the operators on the site. In fact, it seems that board gaming is a staple of the town, which boasts a large comic book and board game store in the uptown mall. Long nights with good local beer and good games were most definitely recurrent.

By the end of my stay, I had invested in a bike to allow myself some freedom. I soon found, though, that warm spring days, long, long roads and a cheap bike bought on Craigslist do not mix particularly well. I rode it into work once, a twenty mile trip that took way longer than expected. Nobody warned me that the whole route was a gentle incline. It was a few weeks again before I rode it home. Afterwards, it was a little worse for wear, but nothing that some TLC couldn't fix. Whilst it was on site, though, it served as a handy tool when making my pilgrimages to the arm ends – a long walk, or a much shorter cycle. And when the bike wasn't at the site, it became my run-around machine. It let me pop to the nearest supermarket to top up on milk, to cycle to the local bar where I somehow managed to become the quizmaster, to cycle into town to read in the park by the river, or to sit and work with a tea in the board game shop.

I have lots of very fond memories of my time as a Fellow. I made lots of good friends who, half a year later, I am still in contact with. I learned lots about the detector, about the people who work on it, and about a different way of life than my own. I would jump at another chance to visit the site, for the place and for the people.

LIGC 2017

I. Fabric

A pastel pattern of pink
and violet wild flowers
lightly outlined in thin charcoal
on a sheet pegged to the clothesline
rippling in the wind over grass
a girthy woman
stretching out her arms
pinching the four clothespins off
one by one
to set the sheet free
But then she holds two corners
and as if whipping a fly
off the nose of a lion
she rides the fabric of motion
with one
loud
flap

he means
I think
the animation
where said earth jiggles like jello
though the kind of Jello one might
find on a Pinterest board
for Earth Day
I googled
all things gravitational
Newton explains
it said
the tides
and I hoped
nobody ever knew
I had never thought
they needed
an explanation

II. Conference

The man in front
of the slide show said
you can see the earth
he said
jiggling like jello
he said
but don't be afraid
he said
and I hadn't been
until he said it
the earth
doesn't really do this
he said
the effect
he said
is greatly
exaggerated

III. Spacetime

All bodies move
to their natural place
The attraction
equal
to the product
of their masses

divided

by the distance
between them
Listen to their whisper in space

ripples in the fabric of their sheets
waves
as two merge
into one.

Heinz Billing passed away on Wednesday the 4th of January 2017 at the age of 102. See Issue 8 (page 18) for a brief recollection of Heinz Billing's early work on gravitational wave detection by Albrecht Rüdiger.

Neil Gehrels passed away on the 6th of February 2017 at the age of 64. Along with his many astrophysical contributions, Neil was the chair of the LSC diversity group and an active organizer of the diversity sessions in our meetings.

Career Updates

Sebastian Khan has finished his PhD in Cardiff and is now a postdoc at AEI Hannover.

Sean Leavey passed his viva in November while spending 6 months on a knowledge transfer placement with a start-up company making high-voltage electronics. He is now back working in Glasgow as a postdoc in Stefan Hild's speed meter group.

Frank Ohme has moved from Cardiff to AEI Hannover, where he now leads an independent Max Planck research group.

Hugo Paris, formerly an engineer at Stanford University, joined 4ms Company in Portland, Oregon, as a developer to design new audio synthesizers. He is also producing his own electronic music under the name Lavender, which you can learn more about here: www.lavendersynth.com, facebook @lavendersf, instagram @hgpr.

Patricia Schmidt has moved from her postdoc at Caltech to Radboud University in Nijmegen.

Amber Stuver has been appointed Chair of the APS Committee on Informing the Public, and Chair of the AAPT Committee on Space

Science and Astronomy.

Andrew Williamson has finished his PhD in Cardiff and is now a postdoc at RIT.

Awards

Awards and recognitions received by LVC members are also being compiled for EPO's new LIGO Awards and Recognitions blog, <http://ligoawards.blogspot.com/>, at <https://wiki.ligo.org/EPO/LIGO Awards>.

The LIGO team has been awarded the **UK Royal Astronomical Society 2017 Group Achievement Award in Astronomy** for the direct detection of gravitational waves by the LIGO detectors.

Science has named the detection of gravitational waves as the **Breakthrough of the Year**. The discovery fulfilled a 100-year-old prediction by Albert Einstein and foreshadows a new way to eavesdrop on the most violent events in the cosmos.

The discovery of Gravitational Waves by the LIGO-Virgo Collaboration was named the **Top Science story in 2016** by ScienceNews Magazine.

The Physics World 2016 Breakthrough of the Year goes to "the LIGO Scientific Collaboration for its revolutionary, first-ever direct observations of gravitational waves".

The Foreign Policy Magazine named The LIGO Scientific Collaboration one of the **100 Leading Global Thinkers of 2016 and a "chronicler" "for opening a window to the dark side"**.

The Advanced LIGO Engineering Team Receives OSA's **2016 Paul F. Forman Team Engineering Excellence Award** for connecting

"optical, electrical and mechanical elements of advanced interferometry to find engineering success at the limits of human endeavor".

The LIGO team receives the **Distinguished Science Award** from the National Space Club - Huntsville Chapter. The purpose of the award is to recognize a scientist or a science team that has made substantial contributions in research and discoveries that expand knowledge and understanding of space.

Sanjeev Dhurandhar of IUCAA, Pune, India has been awarded with the HK Firodia 2016 award on 29th November 2016 for his "outstanding contribution to the discovery of Gravitational Waves".

Bruce Allen, Alessandra Buonanno and Karsten Danzmann were awarded the Lower Saxony State Prize for their "contributions to one of the most important scientific discoveries of the century".

Karsten Danzmann was awarded the Fritz Behrens Foundation Science Prize and the 2016 Lower Saxony Science Award.

Sarah Gossan, a Caltech graduate student, was named the 2016 Caltech Garmire Scholar.

Laura Sampson, a postdoctoral fellow in physics at Northwestern University's Center for Interdisciplinary Exploration and Research in Astrophysics (CIERA), was named a 2016 L'Oreal Women in Science Fellow.

Sheila Rowan of the University of Glasgow received the 2016 Scientific Breakthrough WIRED Audi Innovation Award for playing "a vital role in the design and construction of the fused silicon suspension systems for the LIGO mirrors, which are the most sensitive instruments ever built."

James Hough of the University of Glasgow was presented the Royal Medal by HRH Prin-

cess Anne at the Royal Society of Edinburgh on Friday 9 December for “his invaluable contribution to the field of physics and the study of gravitational waves – ripples in spacetime caused by massive astronomical events such as the collision of black holes”.

Karan Jani, a graduate student at Georgia Tech, was selected as one of 2017’s “30 under 30” personalities in Science by the Forbes Magazine.

Paul Lasky won a Tall Poppy award from the Australian Institute of Policy and Science.

Gabriela González of LSU and the **LIGO team** were awarded the 2017 Bruno Rossi Prize by the High Energy Astrophysics Division of the American Astronomical Society.

Gabriela González of LSU received the Jesse W Beams award from the Southeastern Section of the American Physical Society and was chosen as one of the top 10 “people who mattered” by Nature Magazine.

Gabriela González, David H. Reitze and Peter R. Saulson were awarded the 2017 National Academy Award for Scientific Discovery, for their work as spokespersons of the LIGO Scientific Collaboration.

Fred Raab of the LIGO Hanford Observatory (LIGO Laboratory Associate Director for Operations) was elected a 2017 Fellow of the Optical Society of America “for development of fundamental techniques for interferometric gravitational wave detection and for leadership in LIGO during its transition from laboratory-scale to kilometer scale devices and into its era of gravitational wave astrophysics”.

Rai Weiss, Kip Thorne, and Barry Barish received the 2016 Smithsonian Magazine American Ingenuity Award in Physical Sciences for their work which led to the detection of gravitational waves.

Albert Lazzarini, Jay Marx, and Carmen Menoni were selected as 2016 AAAS Fellows.

Barry Barish and Adalberto Giazotto received the prestigious 2016 Enrico Fermi Prize of the Italian Physical Society “for their fundamental role in the first direct detection of gravitational waves and the discovery of binary black hole mergers”.

In particular:

– to Barry Barish, California Institute of Technology, Pasadena, CA, USA, “for his fundamental contributions to the formation of the LIGO and LIGO-Virgo scientific collaborations and for his role in addressing challenging technological and scientific aspects whose solution led to the first detection of gravitational waves”;

– to Adalberto Giazotto, Istituto Nazionale di Fisica Nucleare, Pisa, Italy, “for his decisive contributions in conceiving and realising the first interferometer with super-attenuators, Virgo, which made possible the quest for gravitational wave sources with an unprecedented sensitivity at low frequency”.

Barry C. Barish and Stanley E. Whitcomb will receive the 2017 Henry Draper Medal. “Together, Barish and Whitcomb led the large and talented team that built the Laser Interferometer Gravitational-Wave Observatory (LIGO).”

2016 APS Fellows:

Frolov, Valery V. (LIGO Livingston)

For his contributions to gravitational-wave physics, in particular the commissioning of the Advanced Laser Interferometer Gravitational-Wave Observatory detector that observed GW150914.

Landry, Michael (LIGO Hanford)

For contributions to the first direct detection of gravitational waves, including leadership of early efforts in detector calibration and data analysis, leadership of the installation of the Advanced Laser Interferometer Gravitational Wave Observatory at Hanford and leadership of its first observing run.

Sperhake, Ulrich (CSIC - Consejo Superior de Investigaciones Científicas)

For important contributions to numerical studies of binary black hole systems, including leading work on recoil velocities following astrophysical mergers, and pioneering efforts exploring the high-speed collision problem of relevance to super-Planck-scale physics.

Vallisneri, Michele (Caltech)

For significant contributions to the statistical theory and computational practice of gravitational-wave detection and parameter estimation, and for cross-fertilizing technical approaches among the ground-based, space-based, and pulsar-timing detection programs.

The Royal Society of Edinburgh honours Scottish scientists associated with the recent discovery of gravitational waves. During its Annual Statutory Meeting on the evening of Monday 31 October the Royal Society of Edinburgh (RSE) recognised the key role that Scottish scientists played in the historic detection of gravitational waves. A total of 16 researchers were awarded the prestigious **President’s Medal** by RSE President Dame Jocelyn Bell Burnell for this outstanding achievement.

Ron Drever FRSE (California Institute of Technology)

For early work at the University of Glasgow on the development of aluminium bar gravitational-wave detectors and their optically-based successors, and for research at the California Institute of Technology leading to the funding of the initial LIGO detectors.

Jonathan R. Gair (University of Edinburgh)

For contributions to the development of the methods used to estimate the rates of black hole binary coalescences based on the observed events.

Giles Hammond (University of Glasgow)

For the implementation on site of the silica fibre suspension elements essential to the low noise operation of the Advanced LIGO detectors.

Martin A. Hendry MBE FRSE (University of Glasgow)

For contributions to the estimation of Advanced LIGO detection rates and significance, and for leading contributions to the global public outreach programme associated with the first detections.

Ik Siong Heng (University of Glasgow)

For leadership of the group which, based on many years of background research, made the first real observation of a gravitational wave signal.

Stefan Hild (University of Glasgow)

For advances in the sensitivity of the interferometry for both the Advanced LIGO and Virgo detectors.

Jim Hough OBE FRS FRSE (University of Glasgow)

For 45 years of research towards the detection of gravitational waves, UK leadership of the German British GEO600 detector development, and development of laser stabilization and mechanical isolation systems essential to the detection of gravitational waves by Advanced LIGO.

Nicholas A. Lockerbie (University of Strathclyde)

For leadership of the work at the University of Strathclyde which resulted in contributions to the electrostatic drive and sensor systems for the control of the Advanced LIGO suspension structures – essential for the subsequent detection.

Iain W. Martin (University of Glasgow)

For development of noise reduction techniques associated with mechanical bonding and optical coatings, essential to the sensitivity achieved by Advanced LIGO.

Gavin Newton (University of Glasgow)

For earlier work on the prototype interferometer at the University of Glasgow and contributions to the GEO600 detector in Germany, which led to techniques adopted in Advanced LIGO.

Stuart Reid (University of the West of Scotland)

For contributions in the area of reducing thermal noise in the suspensions and mirror coatings, essential to the successful operation and detection results from Advanced LIGO.

Norna A. Robertson FRSE (California Institute of Technology and University of Glasgow)

For contributions to the design and development of the suspension systems for Advanced LIGO and for leading the installation of these systems at the detector sites.

Sheila Rowan MBE FRSE (University of Glasgow)

For leading the Institute for Gravitational Research in Glasgow over the critical period of upgrading the LIGO detectors and for contributions to the development of the ultra-low noise suspensions and mirror coatings of Advanced LIGO, without which the detections could not have been made.

Kenneth A. Strain FRSE (University of Glasgow)

For leadership of the UK input to upgrade the LIGO detectors, leading to the detection of the signals from the black hole binary coalescence.

Harry Ward (University of Glasgow)

For earlier, but essential, contributions to the prototype detectors at the University of Glasgow and the California Institute of Technology, in the areas of laser frequency, amplitude and directional stabilization, and for the initial design of the control systems of the GEO600 detector.

Graham Woan (University of Glasgow)

For his sustained leadership role in LIGO data analysis and development of Bayesian inference methods in the collaboration.

LSC Elections

Evan Goetz was elected as the LAAC co-chair in December 2016.

Greg Ogin was elected as the LAAC senior representative in December 2016.

Duncan MacLeod was elected as the LAAC Postdoc representative in January 2016.

Serena Vinciguerra was elected as the LAAC graduate student representative.

Hartmut Grote was elected as the Technical Advisor to the LIGO Oversight Committee in November 2016.

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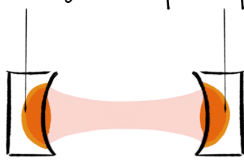
TCS IN A NUTSHELL

Most objects in the world expand when heated and contract when cooled. Even half-a-million-dollar aLIGO optics are no exception when bombarded with >100kW laser power inside the arm cavities.

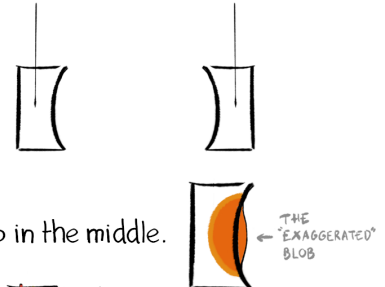
Two things happen when optics are heated: 1) bumps appear on the surface of the optics (causing a change in radius of curvature) and 2) the index of refraction of heated substrates changes, affecting the speed of the incident wavefront and potentially causing mode mismatching.

The question is, what can we do about it?

Here's where the **Thermal Compensation System** comes in. We want to get the optical path back to the cold state of the interferometer.



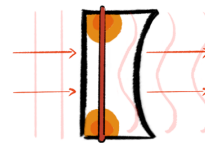
When optics are heated we get this (exaggerated) blob in the middle.



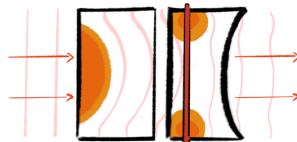
So we installed **ring heaters** to to flatten out the blob!



The problem is, ring heaters take a long time to warm up (~24 hours!) so we have to leave them on all the time, which means early in the lock acquisition process the optics are in a not-so-cold state.

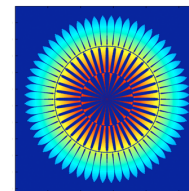


So we use **CO2** lasers to heat the compensation plates behind the test masses.



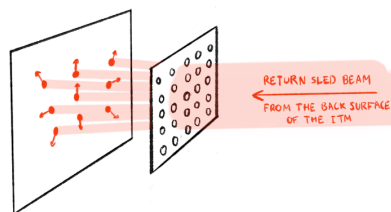
Now the wavefront distortion isn't so bad!

Ring heaters fix the surface bump but don't fully solve the hot spot problem within the substrate. To run at high power (>30W input power) we also need CO2 annular heating. This can heat the compensation plates in various shapes to allow flexible spatial correction.



Cool huh?

Other components of the TCS are the **Hartmann Wavefront Sensors (HWS)**. They're like a cartographer mapping the tiny residual bumps and changes to the surface and substrate of the test mass. To be able to configure the right CO2 power and ring heater power we need to know how much the optic warps so that we know how much we have to compensate. The HWS tell us that..



And that's it. Now you know as much about TCS as I do!