LIGO NEWTON-BHABHA PARTNERSHIP

Progression report 2020

Contents

Introduction

The LIGO India agreement was signed officially at the British Council offices in New Delhi between a consortium of universities in India led by IUCAA (Inter-University Centre for Astronomy and Astrophysics), in Pune, and a consortium of U.K. universities led by the University of Glasgow.

The programme is being funded by the UK's Science and Technology Facilities Council (STFC) through its Newton-Bhabha project on LIGO. It will focus on building capacity within India for the LIGO India detector.

The LIGO India partnership will allow scientists in India to build a third LIGO detector in their country; upscale their entrepreneurial activity through creating more business spin-offs by using applied gravitational wave research; and strengthen India's capacity in the teaching of STEM (Science, Technology, Engineering and Mathematics) through public outreach and school-focused training activities.

This collaborative programme will also enable Indian scientists to work with U.K. institutes for extended periods of time, with reciprocal visits to the India labs to develop infrastructure and provide on-site training, essential to build the capability to deliver a LIGO-India detector.

Highlights

Members: 29

Student exchanges: 11

Business partners: 7

Meetings: 4

Conference presentations: 22

Participation in open days: 2

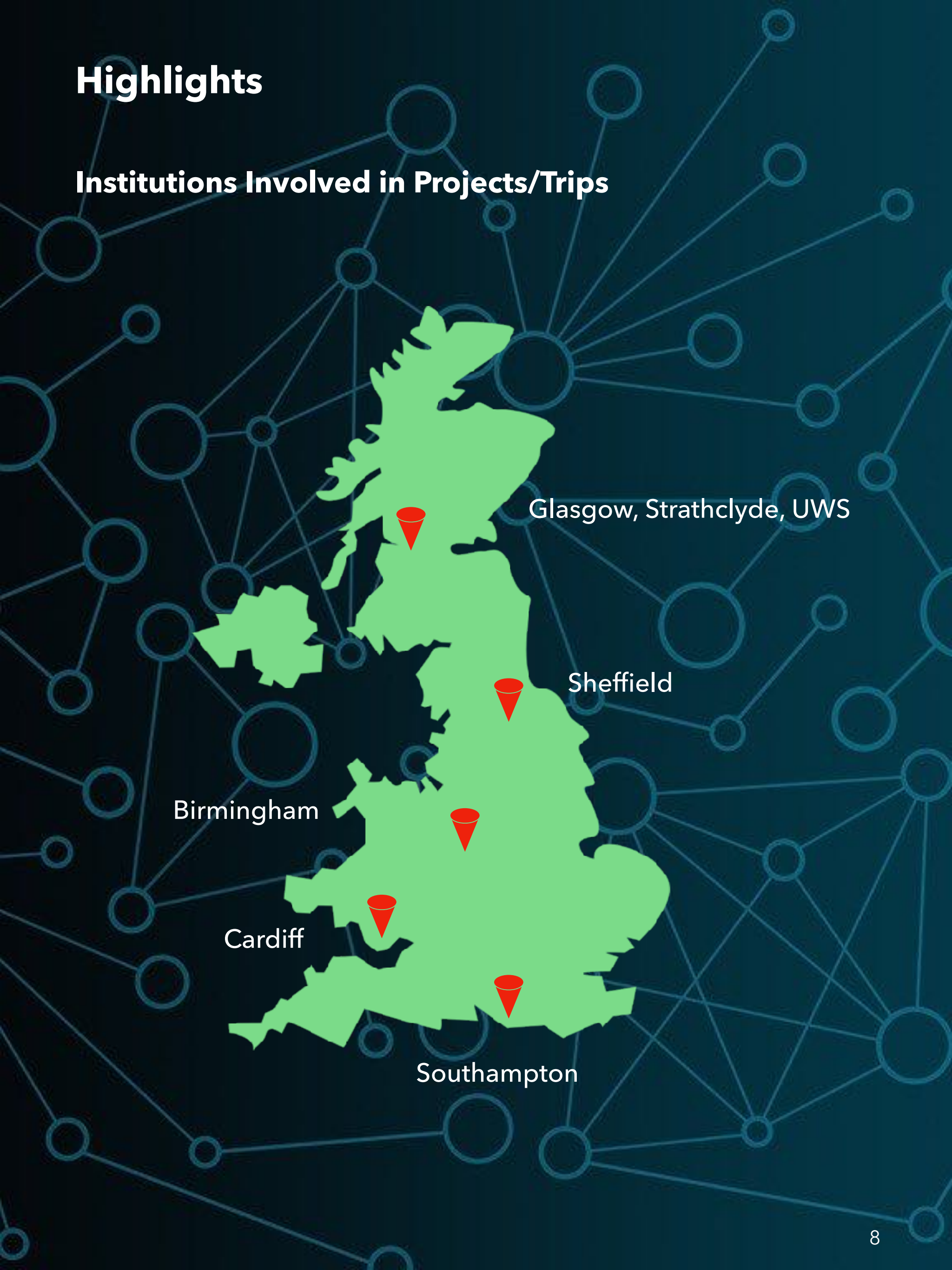
Workshops: 3

Awards: 1

Media articles: 6

Highlights

Institutions Involved in Projects/Trips




IIT Roorke
IICT Gandhina-
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IUCAA, Pune
ISSER, Pune
TIFR Hyderabad
IIT Bombay
IIT Madras
ICTS Ben-
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People of Newton-Bhabha partnership U.K.-LIGO India

Professor Nils Andersson
Applied Mathematics
University of Southampton

Prof Nils Andersson os interested in many problems in general relativistic astrophysics, in particular related to the dynamics of black holes and neutron stars. In the last few years, my main focus has been on neutron stars and issues ranging from the fundamental physics aspects (superfluidity, elasticity etcetera)to observed dynamics(pulsar glitches, magnetar flares and spin-variability in accreting systems). My current research is mainly motivated by the promises of gravitational-wave astronomy.

Professor Sukanta Bose

Senior Professor at the Inter-University Centre for Astronomy and Astrophysics (IUCAA) and the Project Coordinator of LIGO-India at IUCAA.

Sukanta Bose is the Chair of the LIGO-India Scientific Collaboration (LISC) and a member of the LIGO Scientific Collaboration (LSC) Council. He also chairs LSC's Review Team for the Stochastic (signals) Working Group. He is an elected member of the International Society of General Relativity and Gravitation (ISGRG) Committee. Since 2013, Bose has worked on training several LISC (formerly IndIGO) scientists in gravitational wave research, particularly, using LIGO data, and on guiding their contributions in LSC science.

Dr. Liam Cunningham
Research Fellow
University of Glasgow

Dr Cunningham is a full time Research Fellow in the School of Physics and Astronomy at the University of Glasgow. His current position has a 50:50 split between two roles on the ATLAS Project at CERN.

Professor Ed Daw
Gravitational Waves and Dark Matter Physics
University of Sheffield

Prof Ed Daw is currently thePrincipal investigator of the University of Sheffield Gravitational Wave Research Group. HIs research interests include Dark matter searches, Gravitational radiation, Axions, Signal processing, Dynamic wave tracking and Motor control.

Dr. Suresh Doravari
Scientific Officer at IUCAA, Pune, India

Suresh Doravari have a keen interest in pursuing experiments in fundamental physics. That is usually combined with development of novel new sensors, actuators and design of control systems. He has chiefly worked on gravity related experiments, testing the equivalence principle, looking for new interactions, looking for violations of fundamental symmetry laws and such.

Professor Andreas Freise
School of Physics and Astronomy
The University of Birmingham

Andreas Freise is a Professor of Experimental Physics at the University of Birmingham and has recently been appointed as a Professor of Gravitational Wave Physics at the Vrije Universiteit Amsterdam. His main interest is gravitational wave instrumentation, he has been part of the LIGO team for 20 years and is part of the group that conceived and develops the Einstein Telescope project. Prof Freise has developed and maintains the software package FINESSE, which is used worldwide for the design of interferometer systems.

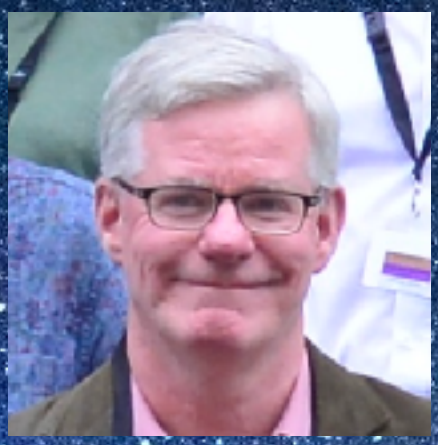
Professor Desmond Gibson
Director of the Institute of Thin Films, Sensors and Imaging
University of the West of Scotland

An entrepreneurial physicist with a first class record in thin film & sensor research, development, production and commercialisation, extending over a thirty year period and gained from technical director/ CEO roles within blue chip companies, SME`s, start-ups and close association with academia. Proven track record in establishing world class published and patented research, development, intellectual property and commercialisation of functional thin film processes, deposition tools, sensors and medical devices. Research activity formerly within industry and latterly academia. Effective knowledge transfer, economic and societal impact from industrial and academic experience.

Professor Giles Hammond
Physics and Astronomy
University of Glasgow

Prof Hammond joined the Institute for Gravitational Research in 2007 as an RCUK Academic Fellow and was promoted to Reader in 2012 and Professor in 2016. He has made significant contributions to the development of the monolithic stages of the Advanced LIGO quadruple pendulums, and has led the installation of several suspensions at both the Hanford and Livingston sites.

People of Newton-Bhabha partnership U.K.-LIGO India



Professor Martin Hendry
Gravitational Astrophysics and Cosmology
University of Glasgow

Prof Hendry's research interests lie in: (1) Gravitational wave astronomy - particularly the use of future gravitational wave observations to constrain cosmological parameters and issues relating to the optimal combination of data from gravitational wave sources and their electromagnetic counterparts. (2) Statistical methods for the analysis of cosmological data sets, particularly large-scale galaxy redshift and peculiar velocity surveys and surveys of high-redshift supernovae. (3) Applications of gravitational microlensing, including diagnosis of planetary and stellar atmospheres, circumstellar envelopes and stellar winds, and the impact of Shapiro delay on the absolute calibration of pulsar timing.

Professor Ik Siong Heng
School of Physics and Astronomy
University of Glasgow

Professor Heng performs research at the forefront of fundamental physics with observations that will uncover the mysteries that lie in the darkest, densest regions of the Universe. His main research focuses on transient gravitational wave detection (eg. from merging binary neutron stars and core-collapse supernovae) and astrophysics.

Professor Sir James Hough. OBE FRS FRSE
Associate Director of the IGR

Prof. James Hough is a graduate of the University of Glasgow where he became Professor of Experimental Physics in 1986 and is currently the emeritus holder of the Kelvin Chair of Natural Philosophy, and also a Visiting Professor in Physics at the University of Strathclyde. He was Director of the University's Institute for Gravitational Research from 2000 to 2009 and is now Associate Director.

Professor Rachel Kalpana Kalaimani
Assistant Professor
Indian Institute of Technology, Madras

Dr Kalaimani obtained a PhD from IIT Bombay, Control and Computing group, Electrical department, in December 2014. She was a post-doctoral fellow in the Department of Electrical and Computer Engineering at the University of Waterloo from April 2015 to November 2016. I am with IIT Madras since December 2016. Her research interests are broadly in System theory, Control, Optimization and Energy systems.

Dr. Mariela Masso Reid
Research Associate
University of Glasgow

Dr. Masso Reid is a Research Associate in the Institute of Gravitational Research at the University of Glasgow. She is the project manager for the Newton-Bhabha effort between the U.K. and India as well as a collaboration between researchers in the U.K. and China. Part of her work is to encourage, foster and develop collaborations between academic institutions as well as encouraging collaborations between academia and Industry. Her research interests have been primarily focused on suspensions, more specifically, the thermal conductivity of hydroxide catalysis bonds and silicon at cryogenic temperatures as well as strength testing of the bonds. She will continue working on the area of suspensions but changing focus to the making of the fibres. She is also currently involve in writing a children's book as an outreach tool for the surrounding areas of the LIGO India site.

Jordan McGinn
School of Physics and Astronomy
University of Glasgow

Mr. Jordan McGinn is a Research Assistant in the Institute of Gravitational Research at the University of Glasgow. He assists in the management for the Newton-Bhabha effort between the U.K. and India as well as a collaboration between researchers in the U.K. and China. His research interests have been focused on the use of machine learning in gravitational wave data analysis, specifically, interested short duration gravitational wave bursts.

Professor Sanjit Mitra
Associate Professor (Scientist F) at the Inter-University Centre for Astronomy and Astrophysics (IUCAA), Pune, India

Professor Mitra research interests include: Sources and searches for long duration stochastic GW background, Efficient detection of Compact Binary Coalescence (CBC), Instrumentation for GW detection, Various activities regarding proposal, site survey and data management of LIGO-India, characterisation and reduction of noise in laser interferometric detectors, planning and design of future detectors, training a new generation of interested researchers in GW detection.
Also involved in Cosmic Microwave Background (CMB) analysis.

Dr. Anupreeta More
Researcher at Inter-University Centre for Astronomy and Astrophysics, Pune, India

Dr. Anupreeta More is working as a Data Scientist at IUCAA. She has expertise in astronomy and big data projects. At IUCAA, she's applying machine learning techniques for searching gravitational waves and studying gravitational lensing of gravitational waves. She is a member of the LIGO and LIGO-India project.

People of Newton-Bhabha partnership U.K.-LIGO India

Professor Anil Prabhakar
Department of Electrical Engineering with a focus on magnonics, photonics and assistive devices.

Professor Prabhakar's research interests include: Quantum technologies and application, Lasers, Optofluids, Magnonics, Spin waves and Assistive devices.

Professor Prabhu Rajagopal
Department of Mechanical Engineering
Indian Institute of Technology, Madras

Professor Rajagopal's research interests include: Ultrasonics for Nondestructive Evaluation, Structural Health Monitoring and Process Control Simulation and analysis of elastic wave propagation and scattering, Robotic and automated inspection and Artificial intelligence in sensing and control

Professor Umakant D. Rapol
Associate Professor
Indian Institute of Science and Research, (IISER) Pune

Prof Rapol's research interests include: Atomic physics and precision spectroscopy, quantum optics and quantum information processing, biosensors

Dr. G Rajalakshmi
Scientific Officer
Tata Institute of Fundamental Research, Hyderabad.

Dr. G Rajalakshmi research interests include: Establishment of ultra low field NMR techniques. Developing optical techniques for the study of spin physics

Professor Archana Pai
Department of Physics, IIT Bombay

Prof Archana Pai is an associate professor at the Astronomy, Cosmology and Gravity group in the Department of Physics IIT Bombay since 2017. She did her PhD from IUCAA, Pune on multi-detector gravitational wave detection schemes. Subsequently she was a Henri Poincare fellow at Observatory of Nice, INFN Fellow at La Sapienza Rome and a postdoctoral fellow at the Albert Einstein Institute, Potsdam Germany where she worked on LISA data analysis, time-frequency based transient searches as well as data analysis with the resonant bar detectors. She secured the faculty position at IISER Trivandrum in the year 2009 and became a member of IndIGO (Indian Initiative in Gravitational-Wave Observations) consortium and was active in expanding the gravitational wave data analysis community in India via conducting various workshops/schools under IndIGO umbrella.

Her broad research area is Gravitational Wave Astrophysics. Her group at IIT Bombay is active in research topics including time domain as well as time-frequency based gravitational wave transient searches, multi-detector schemes with ground based interferometric gravitational wave detectors, probing astrophysics as well as gravity from the compact binary mergers as well as multi-messenger astronomy. She is a member of LIGO India Scientific Collaboration and an author on the Gravitational Wave Discovery paper. She shares the Special Breakthrough Prize in Fundamental Physics, Gruber Prize in Cosmology with the LIGO Scientific and Virgo Collaboration and received N. R. Sen young scientist

Dr. Karthik V. Raman
Reader
Tata Institute of Fundamental Research,Hyderabad

Dr V.Raman research experience has been diverse encompassing areas of physics, chemistry, electrical and material science and engineering. Some areas of research include spintronics, molecular electronics (photovoltaics and OLEDs), semiconductor device physics, analysis of ab initio methods/computational materials modeling (including spin-polarized) to solve challenging device problems, nano materials, semiconductor nanowires, nanoscale device physics for next generation sensor, memory, and logic applications.

Dr. Somak Raychaudhury
Director at Inter-University Centre for Astronomy and Astrophysics (IUCAA), Pune

Somak Raychaudhury is the current director of the Inter-University Centre for Astronomy and Astrophysics (IUCAA), Pune
His research research interests lie in the study of the evolution of galaxies in groups and clusters, and on the supercluster filaments of the cosmic web. He has used optical, X-ray, radio, infrared and ultraviolet observations to understand how the transformations of galaxies are related to their local and global environment. He is involved in developing machine learning algorithms for Astronomical data mining.

Professor Stuart Reid
Head of Biomedical Engineering and Royal Society Industry fellow.
University of Strathclyde

Stuart Reid leads a multidisciplinary team at the University of Strathclyde and is a member of the LIGO Scientific Collaboration and is the elected co-chair for Optics for both the LIGO Scientific Collaboration and the Einstein Telescope consortium. He was elected Fellow of the Royal Society of Edinburgh (Scotland's national academy), and was elected Chair of the Optics Working group of the LIGO Scientific collaboration - both in 2019. Reid's team hold the world record for the fabrication of the lowest absorption amorphous silicon thin films (Birney et al., PRL 2018).

People of Newton-Bhabha partnership U.K.-LIGO India

Professor Sheila Rowan. MBE FRS FRSE FInstP
Director of the Institute for Gravitational Research
University of Glasgow

Professor Rowan is the Chief Scientist Advisor for the Scottish Government as well as the director for the Institute of Gravitational Research. Rowan has an
Rowan research Interests include: Gravitational Wave Detection on ground (GEO 600 and Advanced LIGO); ultra sensitive mechanical systems, and investigation of materials of ultra-low mechanical loss, lasers for Gravitational Wave Detectors.

Jamie Scott
IT Administrator
University of Glasgow

Dr Scott's research research Interests include: Electron microscopy and atomic force microscopy of interfaces. Data acquisition programming in LabView and similar environments.

Professor Tarun Souradeep
Senior Professor
Inter-University Centre for Astronomy and Astrophysics (IUCAA), Pune

Tarun Souradeep has made important contributions and succeeded in creating a strong, sustained Indian effort addressing issues at par with international research in Gravitation and cosmology. The impact of the Indian team led by him is widely recognized, both in the field of cosmology with frontline Cosmic Microwave Background experiments (CMB), and the emergent field of gravitational wave (GW) astronomy. Souradeep is a coauthor of the historic Gravitational Wave discovery paper

Professor Patrick Sutton
Professor at Gravity Exploration Institute
Cardiff University

My research focuses on the detection and study of gravitational waves -- ripples in the fabric of spacetime. These are produced by some of the most violent events in the Universe, such as the collisions of black holes, the explosive deaths of massive stars, and perhaps the Big Bang itself. The detection of gravitational waves by the LIGO observatories has opened a new window on nature, and is allowing us to probe the behaviour of matter and test Einstein's theory of gravity under extreme conditions that cannot (and should not!) be replicated on Earth. My particular specialties are the detection and interpretation of weak signals in noisy data. I am a

Dr. Manasadevi P Thirugnanasambandam
Researcher
Inter-University Centre for Astronomy and Astrophysics (IUCAA), Pune

Dr. Manasadevi P. Thirugnanasambandam is an experimental physicist with expertise in the area of applied optics, laser physics and laser frequency metrology. Her current research interests lie in development of optical systems for precision measurement and advanced sensing. Currently, she works with the LIGO-India team at IUCAA and is actively involved towards various activities related to building of the interferometric gravitational wave detector

Professor Alberto Vecchio
Director of the Institute of Gravitational Wave Astronomy
University of Birmingham

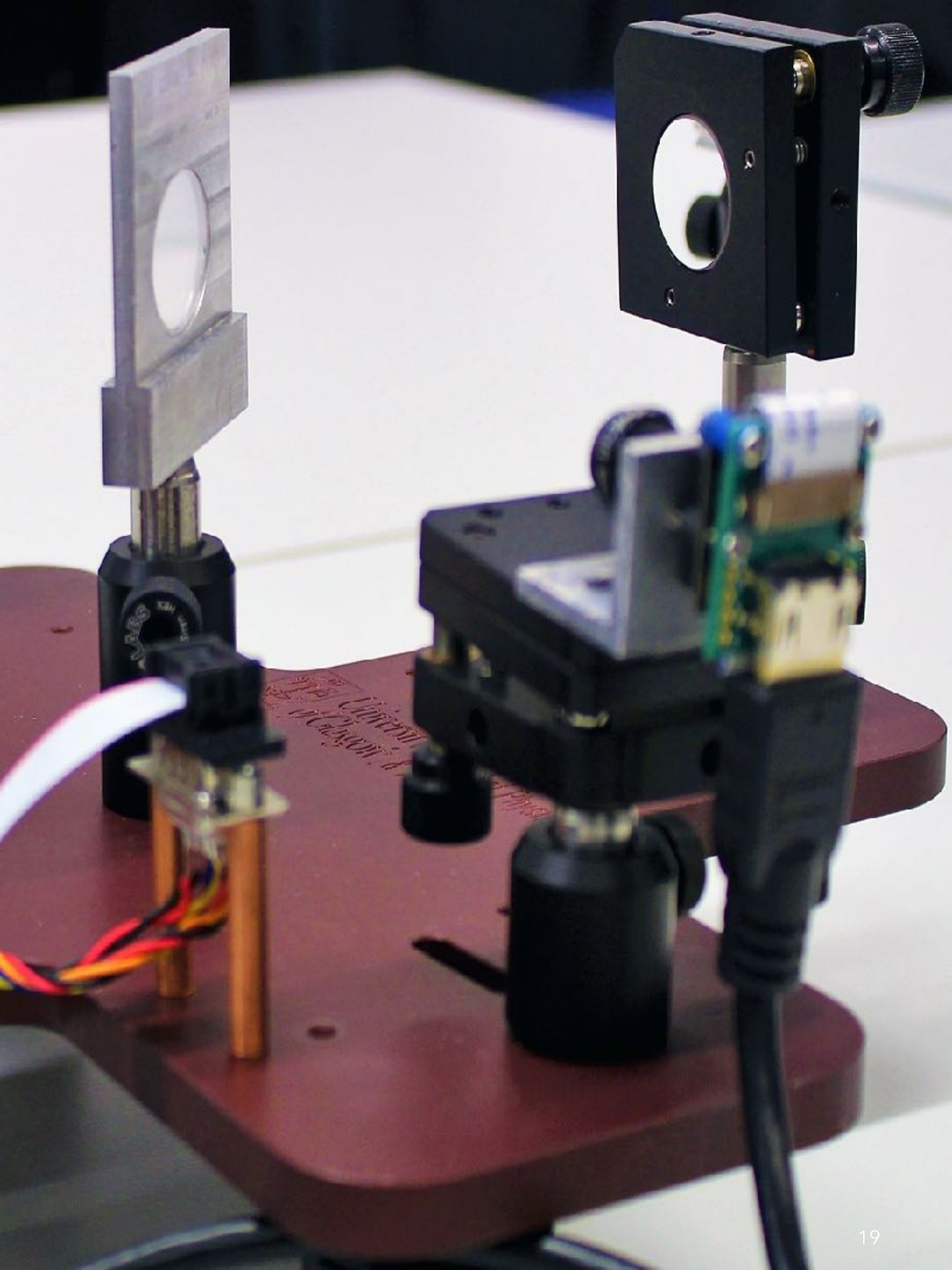
Professor Vecchio's research interests include general relativity, the astrophysics of compact objects - black holes and neutron stars - and gravitational-wave experiments. His work is primarily centred on gravitational-wave science science and new observations of the Universe using gravitational radiation with ground-based laser interferometers (LIGO, Virgo and GEO 600), Pulsar Timing Arrays and future space based interferometers (LISA). He has published over 200 research papers and is a member of the LIGO Scientific Collaboration (LSC), the GEO Collaboration, the European and International Pulsar Timing Array collaborations, and the Laser Interferometer Space Antenna consortium.

Dr. John Veitch
Lecturer
University of Glasgow

Dr Veitch's main research interests are related to the observation of binary black holes and neutron stars with ground-based gravitational wave detectors. He is currently the co-chair of the LIGO-Virgo working group dedicated to this topic since 2015 and have been heavily involved in the analysis of the first gravitational wave detections.

Research & Development

To advance science and technology skills training through learning to develop, operate and exploit LIGO India.



Research & Development

Student Exchanges

"The U.K. has a proven track record in delivering high-quality technology and outreach activities relating to gravitational wave science, including the delivery of key hardware for the LIGO mirror suspensions. A model of sharing knowledge via staff, postdoc and student exchanges to the U.K., together with trips to Indian institutes, will strengthen and benefit the U.K. and Indian academic communities, providing high quality training of the next generation of scientists and engineers." - P.I. Prof Giles Hammond

Nancy Gupta

I am a senior undergraduate student at the Indian Institute of Technology, Roorkee. I was merely a sophomore when I was first introduced to the breathtaking science of LIGO through a webinar by Prof.Rana Adhikari at my institute. Since then, I had a deep desire to learn and contribute to gravitational-wave research. Fortunately, I got a chance to conduct research work on LIGO related project for my bachelor's thesis at the Institute for Gravitational Research (which is part of the University of Glasgow). IGR has world-class labs, and it is actively contributing

contributing to LIGO's coating and suspension. My thesis work at IGR was on stabilisation of 1550nm Laser under the supervision of Prof. Ken and Dr Bryan. . Despite being quite new to the field, the enlightening explanation by Prof. Ken and constant guidance of Dr Bryan in the lab made it easy to work in the sophisticated 10m prototype lab. My time in Glasgow not only equipped me with lab valuable experience and skills but also introduced me to the vibrant culture of Scotland. Working at IGR gave me a clear sense to further pursue research for LIGO; hence I will be starting my PhD from fall 2020 .

Thejas Seetharamu

I started my project work (Supervisor: Prof Giles Hammond) on the fabrication of fused silica suspension fibers as an ERASMUS+ Scholar, with the guidance of Karl Toland. I also got involved in the development of the Sapphire pulling machine, currently in its premature stage, with one of the Ph.D. Students, Jack Callaghan. This fetched me some skills in alignment and beam profiling. Apart from this, I joined one of Prof. Ken Strain's labs for about 15 days, working on Thermo-refractive index noise measurement with Mr. Andrew Spencer and Dr. Borja Sorazu; this fetched me valuable skills in cavity alignment and mode-matching. I also visited The University of Sheffield for about 15 days to work on the development of pre-Mode Cleaner with Prof. Ed Daw.

My summer was unsurprisingly gripping and enlightening; I intend to continue working in the field of experimental gravitational wave astronomy at least for the rest of my undergrad years.

This internship bolstered my acquaintance with and understanding of the physical world. I was exposed to a new work culture in a very dynamic atmosphere. I fetched a lot of skills and experience which could be potentially deployed during my semester projects at IISER Pune as my projects in CGPA (IISER – IUCAA Collaboration) are quite relatable with that in the summer.

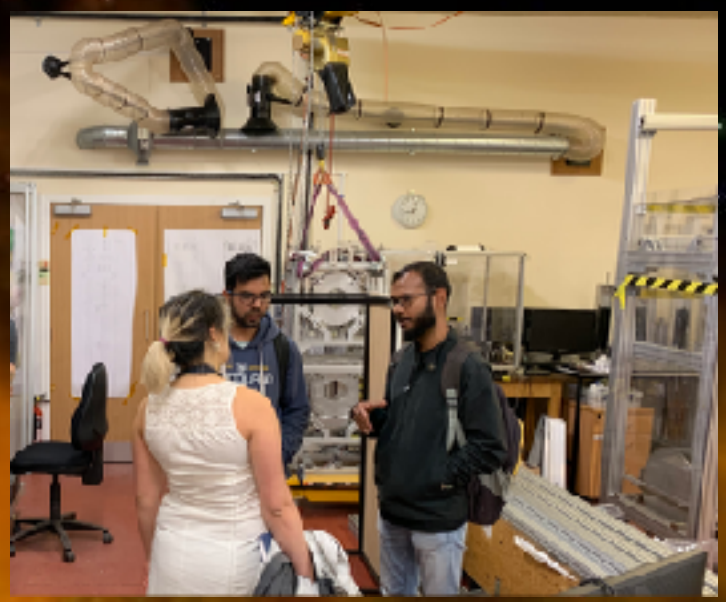
Apart from good research exposure, cultural diversity in a very healthy atmosphere always kept my morale up during my time here.

Student Exchanges

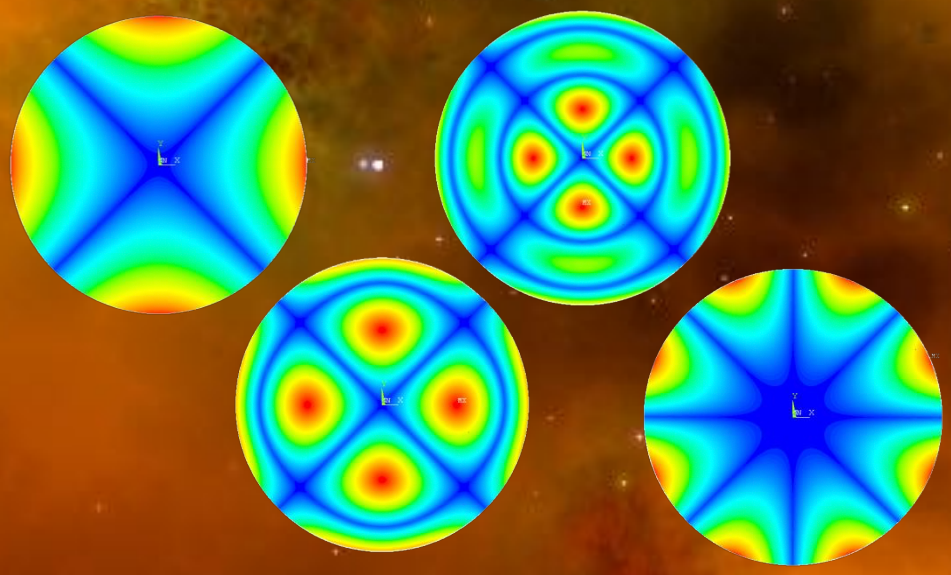
Chetan Vishwakarma (IISER Pune) and Jamney Jay Panda (TIFR)

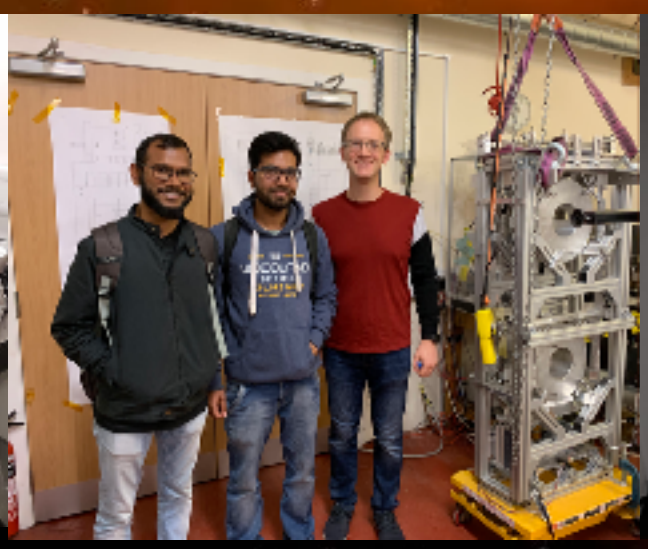
Project Summary

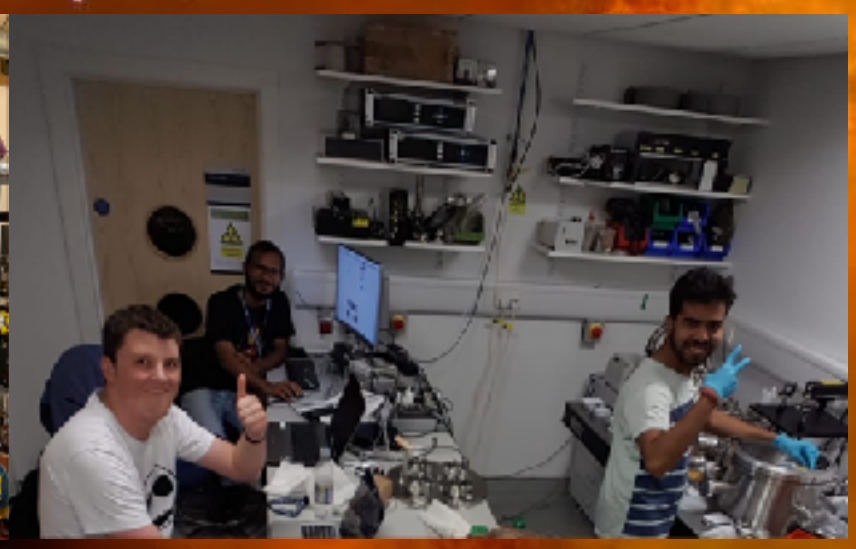
Jamney and Chetan helped build and commission a new measurement system (vacuum nodal suspension set up) for characterising the mechanical dissipation in optical coatings at the University of Strathclyde . As part of this, they became familiar with mechanical ringdown techniques and the related analysis to calculate the thermal noise performance of potential coating materials for future gravitational wave detectors.



Chetan then traveled to the University of Sheffield to continue the work started by Thejas to develop a laser stabilization system, becoming familiar with how the system works as well as to how to set up from scratch.





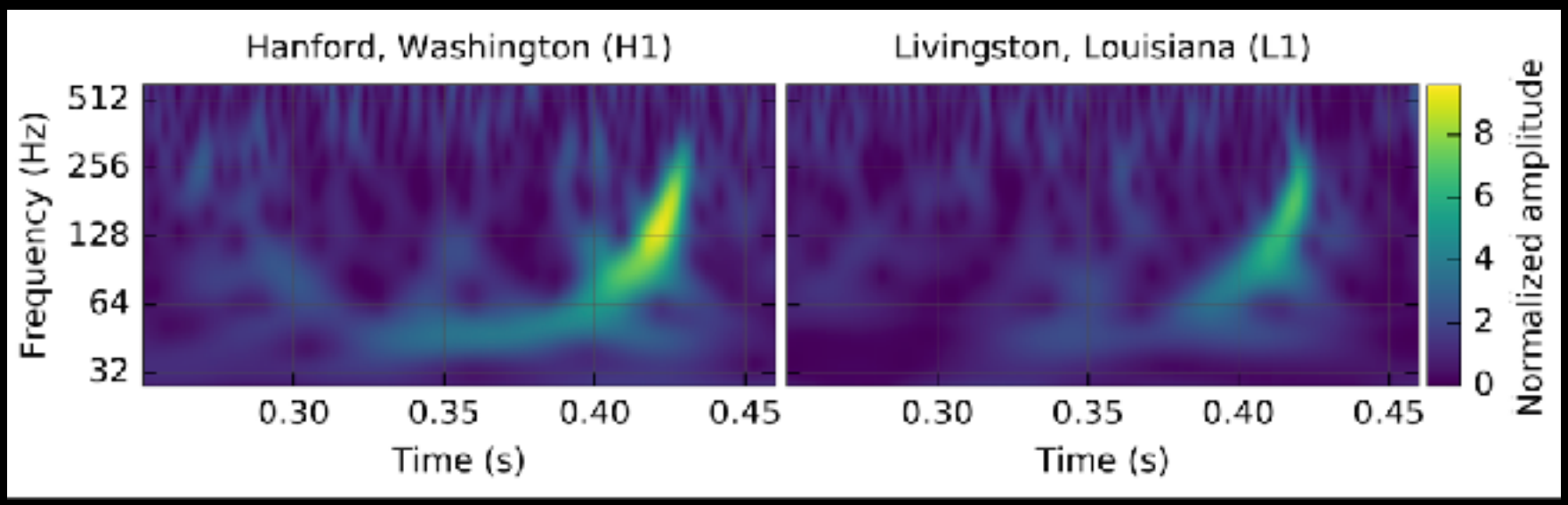


Research & Development

Enhancing search sensitivities with machine learning

Short duration Gravitational wave transient searches in data from the Advanced LIGO and Advanced Virgo detectors are carried out by time-frequency algorithms which capture the temporal and spectral features of the transient. The transient search algorithms have been employed with much success, in particular Coherent Waveburst which made the first detection of gravitational waves from two merging black holes (GW150914). However, transient searches can be hampered by spurious excess noise transients mimicking gravitational wave signals, reducing the search sensitivity.

Prof. Archana Pai (IIT Bombay) and Prof. Ik Siong Heng (University of Glasgow) have formed a collaboration through the Newton-Bhabha framework to explore the use of machine learning techniques to enhance gravitational wave transient search sensitivities. Most recently, through multiple exchange visits supported by the Newton-Bhabha fund, Pai, Heng and collaborators have developed a method based on Gaussian Mixture Models which can significantly enhance the sensitivity of Coherent Waveburst. They have jointly published a journal article describing their approach and are now working to implement this new approach into Coherent Waveburst searches performed on data from the Advanced LIGO and Advanced Virgo detectors.

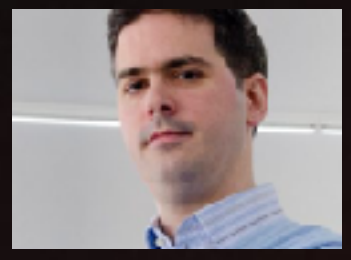


Background credit: LIGO/Caltech/MIT/Sonoma State (Aurore Simonnet)
Figure credit: PhysRevLett.116.061102

Research & Development

LIGO in your hands

Dr. Borja Sorazu developed and built 'LIGO in your hands'. This is a highly portable and interactive Michelson interferometer of low power consumption, that is ideal for demonstrating the essential parts of a gravitational wave detector and it can be used as a tool for teaching interferometry and interference, feedback and control, or even as a demonstration tool for precision measurement.



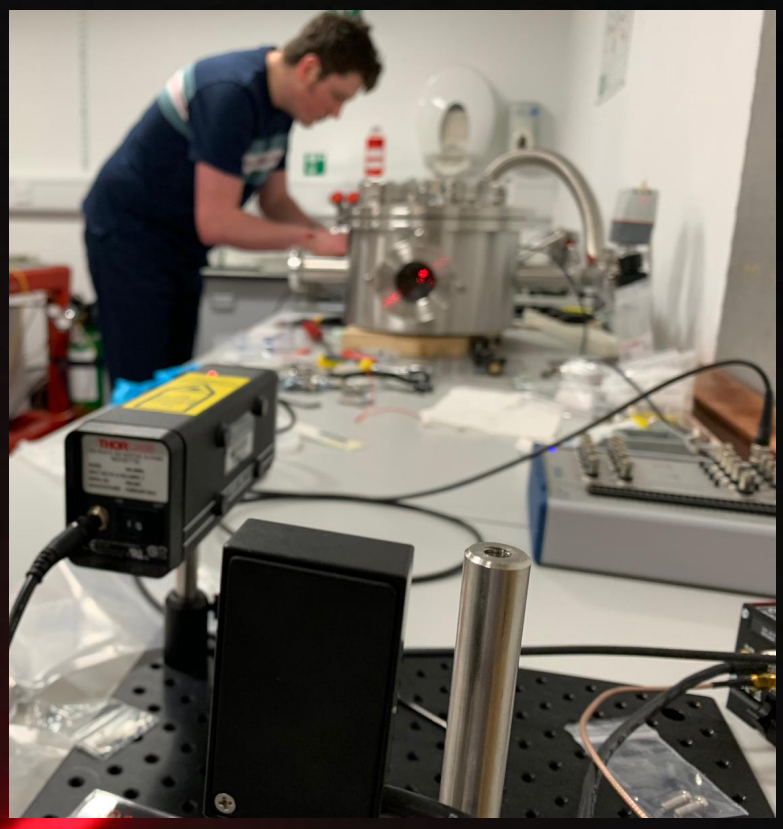
The user interaction is facilitated by a touch screen and an exclusively designed GUI that also provides HD video playback capabilities which can be displayed on the integrated touchscreen or any projection device (through the HDMI output provided on the control box). A camera and a photodiode are used to monitor the interference pattern and provide input signals to a microcomputer (a single Raspberry Pi) that actively controls the interferometer, being able to stabilise it and lock it to any point of its interference pattern.

The device can record perturbation from external disturbances. For example, if that disturbance is a sound wave, then the device becomes a microphone, being able to play back the sound recorded through the light. The GUI provides optical alignment functionalities and post-processing of the recorded data without the need of any additional equipment.

LIGO in your hands is powered by a single standard power supply 5V, 2.5A and therefore it can run on a conventional power bank for hours. The optical layout is robust and does not typically need realignment.

The LIGO in your hand devices are incredible flexible and will serve as both outreach tools during exhibitions as well as being suitable to be used in student laboratory as a tool to understand how a Michelson interferometer works using gravitational wave signals and similar features to those used in gravitational wave detectors as already mentioned. Dr. Borja Sorazu developed the device along with Dr. Angus Bell and Matthew Wassell

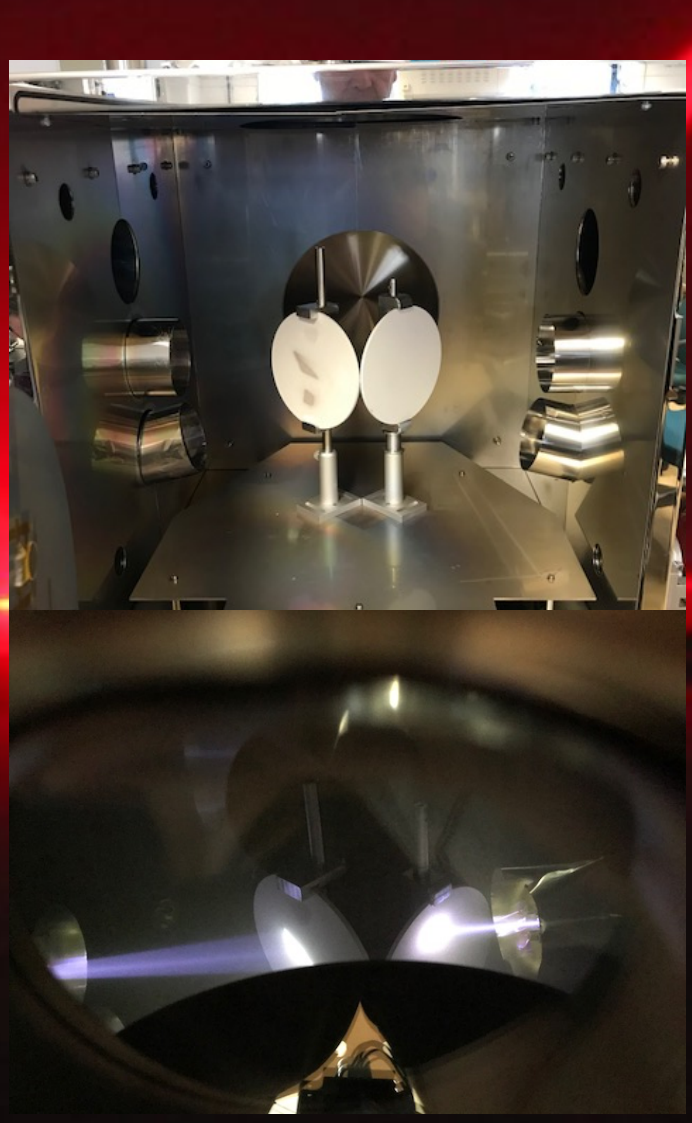
Q-measurement system



A Q-measurement tank was set up at the University of Strathclyde with the help of exchange students, Chetan and Jamney, supported by Strathclyde staff, Prof. Stuart Reid and Dr. Paul Hill. The students learned how to measure the Quality ("Q") factor of coated glass resonator samples, and learned how to calculate the internal friction in the coating layers applied to the resonators.

The system was shipped to TIFR Hyderabad and commissioned in their laboratories. A second (nominally identical) Q-measurement tank already exists in the University of Strathclyde, and helps provides training of future students, in addition to supporting cross-checking of results.

The measurement of the internal dissipation in the thin film optical coatings is essential for the development of future gravitational wave detectors, as it allows an important source of noise to be estimated – thermally driven displacements of the front surface of the mirrors, known as Brownian noise.



Coating targets

The optical coatings required for gravitational wave detectors are fabricated by a process called ion beam deposition, where energetic ion beams are used to knock atoms off a target material, producing a spray of material that can be used to manufacture thin layers with precise optical properties.

The Newton-Bhabha project paid for 6 different target materials, identified as the most relevant materials for the "Advanced+" gravitational wave detectors, such as LIGO India. This has enabled all of the visiting researcher from India, who spent time in the University of Strathclyde, to get hands-on experience of manufacturing and optimising various optical coating technologies, and supports the ongoing collaborations between various labs in the UK and India who are working in optics.

INDUSTRY & COLLABORATIONS

The development of precision instrumentation and novel data analysis algorithms for extracting astrophysical information has led to a number of spin-off applications.

A direct applied spin-off from the gravitational wave work on suspension modelling/development is the development of high sensitivity MEMS gravity sensors. These devices are fabricated using standard micro/nano fabrication techniques and approach sensitivities of 30 ng in a 1 s interaction time (for comparison, the accelerometer in a mobile phone is 1000 times less sensitive). The combination of expertise in precision opto-mechanical systems (Institute for Gravitational Research) and Micro-NanoFabrication (James Watt Nanofabrication Centre) has enabled a transformative technology in gravity imaging. The work has received funding from the Royal Society Paul Instrument fund, the STFC Global Concept Challenges fund, and is currently supported via an EPSRC QuantIC grant under the UK Quantum technology programme.

There is significant company engagement from the oil & gas industry (Bridgeporth, Tullow Oil), environmental monitoring sector (USGS), defence & security (QinetiQ, DSTL, Thales) and space applications (Clydespace). Particular application areas include Oil & Gas prospecting, environmental monitoring of buried waste/water acquefars, seismic surveys for high speed rail, monitoring hidden tunnels/sink holes for the defence & security/civil engineering sectors, and imaging magma buildup in volcanic calderas.

AAC CLYDE SPACE

HELIA PHOTONICS

GSS Gas Sensing Solutions

THALES

HELIA PHOTONICS

Helia's work with high power lasers (we process 750k a month) and the requirements of gravitational wave detection components share many of the same problems, Helia Photonics currently collaborates with several higher educational institutions (including the University of Glasgow) where there is a technology overlap.

"The interaction with the staff at IUCAA was very positive, the campus itself beautiful but there were few members from the optics community at the event Caspar attended. No projects/collaborations have resulted from the visit but Helia's interest certainly remains and the overall experience was a positive one."

Caspar Clark, CEO of Helia Photonics, a leader in coatings for semiconductor devices, optical fibre ends and free space optical components.

Over the past 18 years, Helia Photonics has developed a loyal customer base of more than 350 worldwide and now operates out of a 8,000 ft2 purpose-built, state-of-the-art facility in Livingston, Scotland. During this period, the company has expanded its range of coatings from ultralow anti-reflection (AR) coatings for external cavity lasers to laser lifetime-enhancing protective facet coatings and optical coatings for fibre-ends, micro-optics and supporting services for diode lasers.

Gas sensing solution Ltd are an engineering and technical team with experience on solid state carbon dioxide gas sensors development.

Gas Sensing Solutions Ltd is already partnered with the Universities of the West of Scotland (UWS), Strathclyde and Glasgow, through tech transfer from Stanford, to develop novel crystalline optical coatings that could provide significant benefit for future gravitational detectors. This technology will also have significant relevance to industry for use in integrated optoelectronic devices.

GSS have a strong track record in engaging with the academic sector, having been shortlisted for the "KTP Best of Best" awards (2015), winning the IoP Physics Innovation Award (2014), and securing collaborative grants from Innovate UK, Censis, and the Royal Society.

They are keen to share their experience and expertise to both Indian and British based scientist within this project, to support the proposed research and innovation, particularly as they consider possible routes to commercialisation.

Prof. Desmond Gibson Director of the Institute of Thin Films, Sensors and Imaging at UWS former CEO of GSS joined Caspar Clark and others companies as well as the academic researchers at a meeting held in India in 2019 where discussions were held as to what is needed for the future of LIGO India.

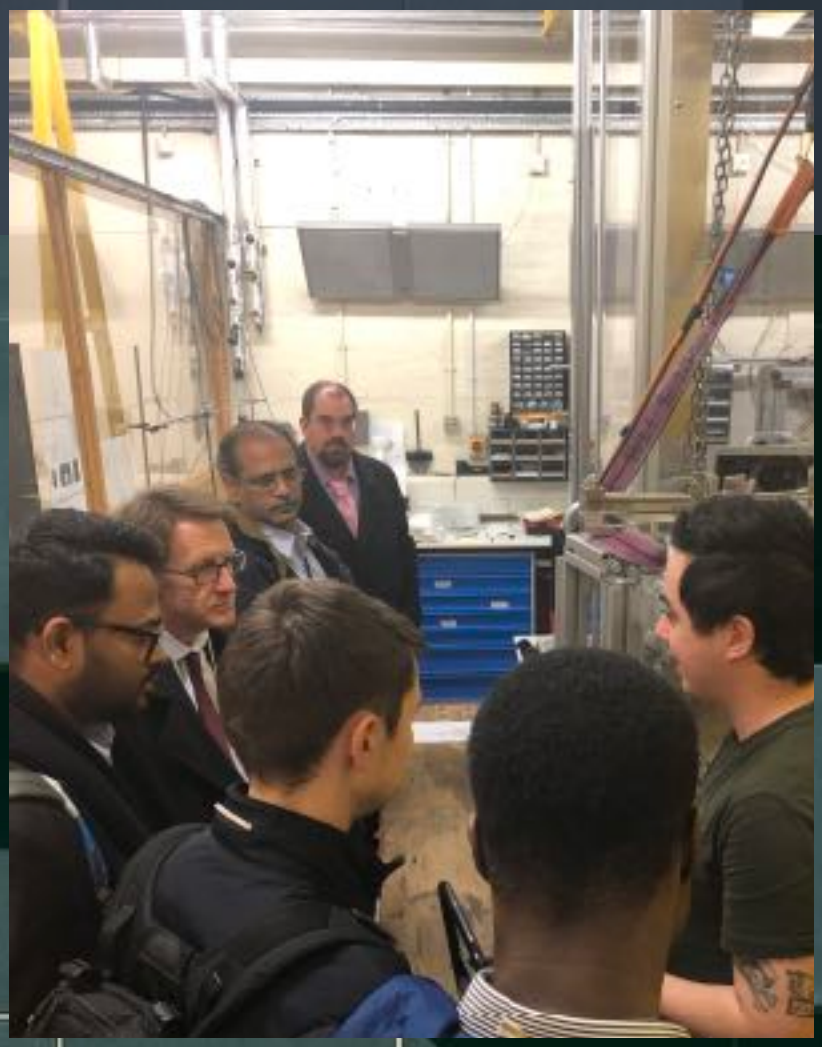
Successful engagement between industry and academic research has been established. This was facilitated from the first face to face meeting in Glasgow in July 2018 and reinforced at the second face to face meeting held in India in Jan 2019 where various Indian companies presented their work as well as having British companies attending, including Gas Sensing Solutions Ltd. (GSS) and Helia Photonics Ltd.

Furthermore, the entrepreneurial activities were solidified on a follow up meeting held in the U.K. in April 2019, where companies including Clyde Space, Helia Photonics, and GSS were actively participating alongside members of the collaboration from both the U.K. and India in addition to a consortium from the British trade Office in India.

The meeting concluded with a visit to TWI Ltd. to investigate the services they offer to other industries. They were also introduced to the various divisions within the company (electron beam, laser, sheet, and arc fabrication/welding processes) and areas of mutual interest were highlighted and interest on internships and graduate student support was shown.

New discussions between U.K. academics and U.K. industry were also initiated through these meetings, leading to a Royal Society Industry Fellowship between the University of Strathclyde and Helia Photonics in 2020, which aims to engage with TFIR Hyderabad and IISER Pune on optical coating technologies for GW detectors.

Collaborations between industry and academic research will continue to be facilitated by the Newton-Bhabha partnership between the U.K. and India to support the success of LIGO India as well as to encourage development of commercial opportunities that will help create high-tech jobs and provide economic benefit in India.



EDUCATION & OUTREACH

LIGO-India's Education and Public Outreach inspire and educate the general population about the nature of our Universe and explain how the scientific method works and can be trusted.


A
gentle
izard

EDUCATION & OUTREACH

Masterclasses in Relativistic Fluid Dynamics: From formulation to simulation

In July 16th-19th 2019, our collaborators at the University of Southampton organised a series of lectures by internal and external speakers about relativistic fluid dynamics and applications to the physics of neutron stars. The event brought in speakers and students from several Indian institutions to discuss a range of topics relevant to the modelling and numerical simulation of fluids in a live spacetime. The includes the underlying physics (starting from fundamental principles) as well as advanced topics (like superfluidity, dissipation and resistivity) and practical issues relating to numerical simulations (different numerical methods and approached to spacetime evolutions.

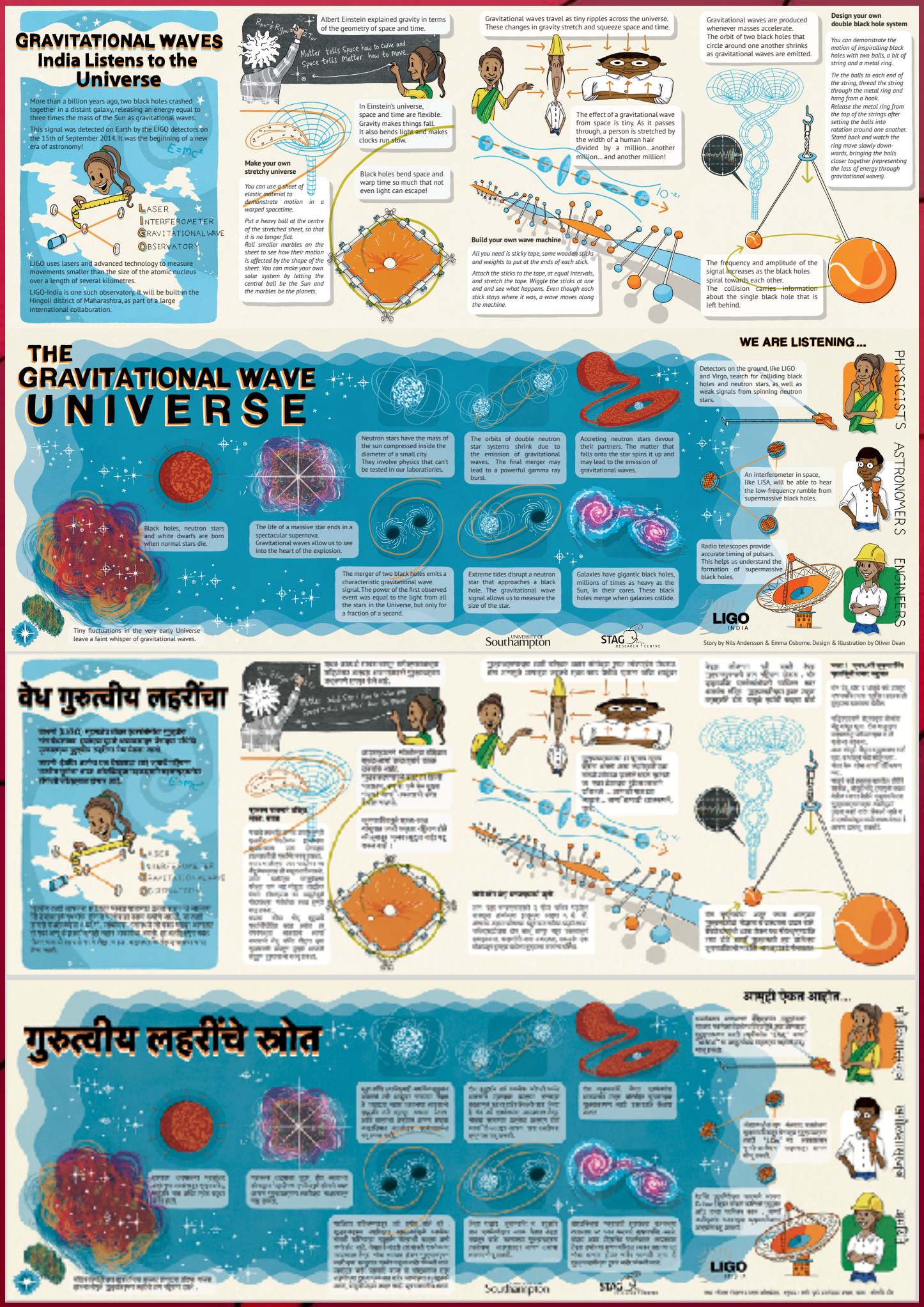
Practical "exercises' drew on the extensive material available within the Einstein Toolkit and the Open Astrophysics Bookshelf and selected depending on the interests of the students. The event was to be interactive as possible (as we also want to learn!), and gratefully accepted contributions from as many of the participants as possible.

The aim of the masterclass was to explain what enters into state-of-the-art numerical relativity simulations of neutron star mergers and investigate what is required in order to develop more realistic simulations. Students were given the opportunity to present their own research in an informal and collaborative set up.

Various experts in the field were invited to take part and give the lectures, such as LIGO member, Greg Comer. Students attending the masterclass were from India, China and the U.K

Gravitational Wave Leaflets

The Newton Bhabha grant has provided funding to produce outreach leaflets that will be distributed to Indian locals who are curious about gravitational waves and the LIGO India interferometers. The leaflets, created by Nils Andersson, Emma Osborne and Oliver Dean, show how gravitational waves are produced and how the next generation LIGO-India observatory will be able to detect these cosmic events. An English version has already been produced with translations to Hindi and Bengali well underway.



EDUCATION & OUTREACH

GW @ Home Lecture Series

A series of online lectures on gravitational wave research and spin offs have been on going since the current pandemic crisis in order to keep momentum and interest. There have been a mix of speakers from both the U.K. and India and positive feedback has been given from this talks. The talks are given live and uploaded on YouTube on the LIGO-India YouTube channel for those that have missed the talk. Everyone from students, postgraduate students to academics and the wider public are all welcome to join the talks, with no registration required and from their safety of their own home.

LIGO-India YouTube Channel:
https://www.youtube.com/c/LIGOIndia

The Vigyan Samagam MegaScience Exhibition

A two months long science exhibit, showcasing India's involvement in global Mega science projects, the multi-venue science exhibition visited four major cities, Bengaluru, Delhi, Kolkata and Mumbai and was opened to the public from May 2019 to March 2020. The event was co-organized by the Department of Atomic Energy, the Department of Science and Technology and the National council of Science Museums.

Dr David Reitze (Executive Director of LIGO Laboratory) and Prof Patrick Brady (current LIGO Scientific Collaboration spokesperson) gave the inaugural talk for the exhibition. LIGO India was amongst those with a booth, with university students as volunteers and hands on demonstrations such as the *LIGO in your Hands* interferometer, providing an excellent platform to engage with students and members of the audience of all ages as well as academics and industrial participants.

National Science Day

The Inter-University Centre for Astronomy and Astrophysics, Pune, India (IUCAA) takes its research to the masses through an Open Day on February 28 every year. This day is also popularly recognised as National Science Day (NSD). Anyone can visit the campus to attend and participate in popular science exhibitions, lectures, demonstrations, screening of scientific films, Q&A sessions etc. Work at IUCAA is showcased through a poster exhibition. A sky watching session wraps it up.

For decades now, IUCAA has been organising this programme regularly and this year saw some UK collaborators attending the event funded through the grant.

EDUCATION & OUTREACH

Open Data Workshop at IUCAA

The Newton-Bhabha - Open Data workshop was held at IUCAA during December 2019.
The workshop provides an opportunity for students, postdocs and other academics interested in gravitational waves as well as others interested in doing science with the LIGO-India observatory.

Experts in the field of gravitational waves were involved with speakers from both the U.K. (Giles Hammond, Martin Hendry, Chris Messenger and Ik Siong Heng) as well as from India (Somak Raychaudhury, Sukanta Bose, to name a few) as well as other members from the International LIGO collaboration such as Fred Raab. The speakers expertise ranged from experimental, to data analysis and theoretical gravitational waves, given a rounded picture of what is required in order to do gravitational wave research. In addition, EPO efforts, scope and collaboration with LI-EPO were also discussed.

A hands-on session was organised as part of the Open data part of the workshop some of the sessions included working on the basics of GW data, applications of deep learning to to classify BBH signal vs. noise and a non-standard yet improved data analysis pipeline.
Experimental sessions were also held in parallel where the main topics were on LIGO coatings research and cryogenic suspension technology and crucial discussions on the stringent requirements and timelines faced for the next generations gravitational wave detectors were held.

Key research areas were highlighted were involvement from the Indian research community can be of help as well as members of LISC and LI-TRD explained the urgent need for trained manpower with the upcoming LIGO-India detector as well as possible solutions to problems in next generation LIGO controls.

The sessions were attended by PhD students, postdocs and a couple of Masters students, primarily, from various parts of India and from IUCAA with over 60 participants.
The organising committee was co-chaired by Anupreeta More and Manasadevi Thirugnanasambandam.

Finesse Workshop

As part of the LIGO-India training program, IUCAA conducted a FINESSE Hackathon for students from colleges across India in March 2020 under the aegis of the Newton-Bhabha program, an Indo-U.K. collaboration. FINESSE is an advanced gravitational-wave detector simulation software widely used within the global gravitational-wave community and is used to model interferometers such as Advanced LIGO, Virgo and KAGRA. This fundamental tool is used to explore new designs for future detectors as well as troubleshoot the present-day detectors in improving their performance. 'Hands-on Interferometer Modelling' is a good way for aspiring young researchers and college students to acquire a detailed knowledge of LIGO-like detectors and the mathematical modelling of such complex optical interferometers.

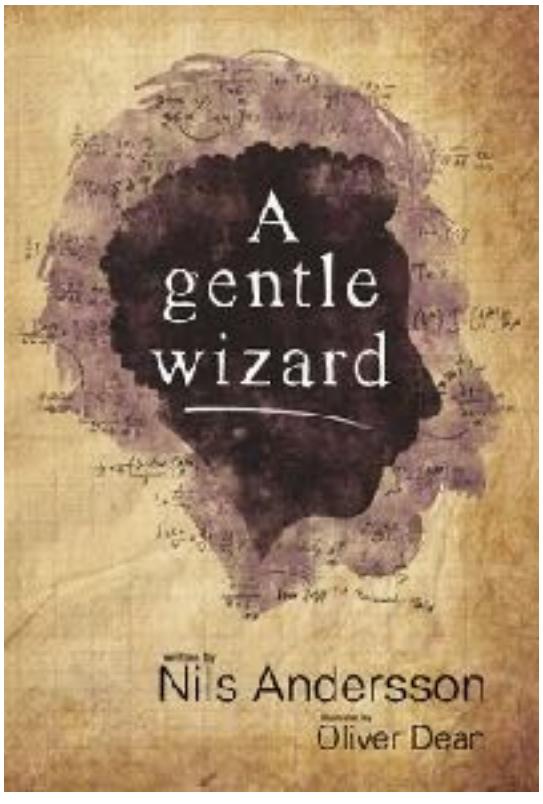
The FINESSE Hackathon 2020 was preceded by an in-depth training program under the mentorship of professional researchers from the international group of FINESSE experts. Anna Green, Philip Jones, Sean Leavy and Gautam Venugopalan held a focussed FINESSE Workshop in December 2019 at IUCAA to bring the selected students and researchers together and impart intense hands-on training. Several web-based tools and workbooks were developed by the mentors so that the students may work through them at their own pace. This material serves as training material for future workshops and wider online resources as well.

The winning team of this FINESSE Hackathon would have the opportunity to go for a two-week internship at one of the LIGO Scientific Collaboration institutions in Europe once international travel resumes.

To sustain interest and encourage students across India to take up modelling interferometers we would be shortly announcing a FINESSE Club, where interested students would be encouraged and mentored to take up interferometer modelling projects.

EDUCATION & OUTREACH

A Gentle Wizard



An entertaining and personal introduction to Einstein's universe. Starting with a walk through Bern in 1905 and ending with the recent discovery of gravitational waves from colliding black holes, this book exposes the theory of Relativity in a readable style. Supported by insightful and zany illustrations, this is a great science story for everyone and anyone.

As a young boy, Jack is sent to deliver a set of pictures to a house on Princeton's Mercer Street. The house is quite ordinary, but the man who lives there is not. Far from it. It is Albert Einstein, perhaps the smartest man in the world. The man that bent space and warped time.

The first chance meeting leads to an unexpected friendship. Jack becomes a regular visitor to the famous professor's home. Together they set out on a journey that explores the professor's ideas about space, time and gravity. The journey takes them to the edge of reality, where clocks grind to a halt and stars collapse onto themselves to form holes that aren't quite holes.

Professor NILS ANDERSSON, an expert on Einstein's relativity, teamed up with the talented illustrator OLIVER DEAN to bring you a personal journey through Einstein's universe. A gentle wizard is now available as e-book and paperback.

Nils explains: The book is a blend of fact and fiction. The science is very much real. So are most of the characters; including Einstein himself, his assistant Helen Dukas, Robert Oppenheimer and John Wheeler. The story builds on things that actually happened, although perhaps not in this particular order or involving precisely these individuals. Jack is entirely fictional. He had to be.

The story may be a bit unusual.

It started as a vague idea. Nils thought it would be nice to write something to celebrate the 100th birthday of Einstein's theory of gravity. This might not make sense to most people – you don't just wake up one morning thinking this would be a great plan – but if you have spent nearly three decades working on problems involving the famous professor's brainchild, your mind might be just a little bit warped. But as soon as he started thinking about it he realised it was going to be tricky.

After a lot of reading, the book was written with this quote in mind. The book is an attempt to tell the story of Einstein and his theory through dialogue and anecdotes, making as much use of actual quotes as possible. The idea was to let the human aspects take centre stage and explain the science as the story developed. This turned out to be a real challenge. Piecing things together, trying to make sense of the science and at the same time not losing the human side, required a lot of hard work. Of course, it was also enormous fun.

A gentle wizard would not have been the same without Ollie Dean's fabulous illustrations. Or, indeed, his feedback during the long editing process.

When he is not drawing Einstein, Ollie produces live-performance artwork and public participation projects. His clientele are as diverse as his work having collaborated with businesses, charities and educators. He has also authored, illustrated and self-published two picture books for children.

A gentle wizard was released in January 2017. It has already received good reviews and should be suitably for - just about - anyone and everyone. The style may work particularly well for young teenagers, but the science explanations should work for anyone interested in Einstein and his ideas. There is also a very human story about friendship hidden somewhere.

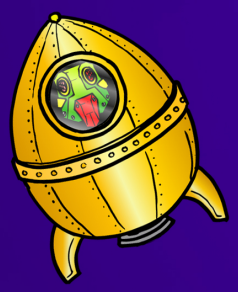
In 1970 C.V. Vishveshwara, affectionally known as the "black-hole man" of India, was working on an obscure piece of astrophysics called gravitational radiation. He predicted that the radiation emitted by the collision of two black holes will have distinct looking patterns. This study was proven right when decades late in 2015 the first gravitational wave was detected with precisely such a pattern. Vishveshwara wrote three single authored ground breaking papers, published popular science books, was an accomplished cartoonist and, now, is remembered in dedication through Prof. Nils Andersson book "a gentle wizard".

EDUCATION & OUTREACH

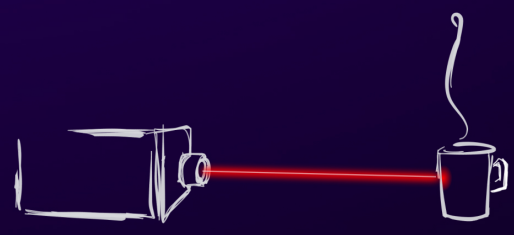
Space Time Quest is a fun game developed by gravitational wave scientists working in the LIGO collaboration (see `A Brief History of Space Time Quest'). The game puts you in charge of designing your own gravitational wave detector. You make choices and trade-off decisions to select the best technology while keeping an eye on the budget. The game is casual but addictive: you can reach the first score (how many gravitational waves did you detect) in just a few minutes. But then you want to go back and try for the highest score, knowing that LIGO scientists are in the gravitational wave high-score hall of fame as well. Can you beat them, literally, at their own game?

Space Time Quest can be played in English, Spanish, Catalan, Dutch, German, Chinese, French, Italian, Russian, Japanese, Hindi and Brazilian Portuguese! If instead you are more interested in studying the underlying equations and Python code, see below for our open source version: Space Py Quest!

SPACE-TIME QUEST



Space Time Quest puts you in charge of designing your own gravitational wave detector. You make choices to select the best technology while keeping an eye on the budget. You can create your detector in just a few minutes. But for the highest score (based on how many gravitational waves you can detect), you need to finely tune your design. There are many scientists from LIGO and Virgo in our high-score hall of fame, can you beat them, literally, at their own game?



Download the free app at:

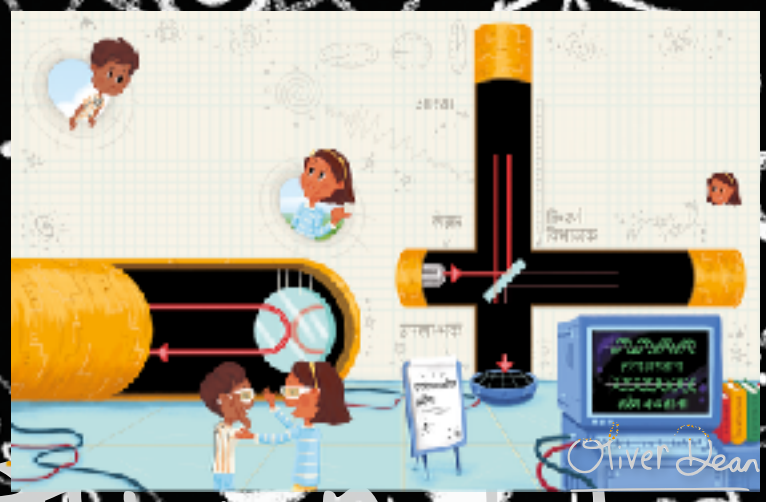
www.laserlabs.org

EDUCATION & OUTREACH

Listen to the Universe

Listen to the Universe is a children's GCRF (Global Challenges Research Funds) funded project. Taking the reader into a journey of discovering gravitational waves. Lila explains to her brother what gravitational waves are, how they originate, Einstein's theory as well as taking us to see the LIGO India site and inside a detector!

The book is filled with flaps that open to reveal amazing images of astronomical events, pull taps to mimic how mirrors move in the detector as well as an impressive 3D pop-up of black holes colliding! The idea of the book is to help encourage children, particularly between 6-8 years old, in India to be curious about astronomy. There is a unique opportunity to promote STEM subjects during the building of the *LIGO India* gravitational wave observatory and this book is a crucial tool for this. Furthermore, local communities to the observatory site are of lower socioeconomic status, and this is an important time to create positive, long-term partnerships and to demystify science.



Oliver Dean

Dr. Mariela Masso Reid - is the PI of GCRF grant awarded to make this book a reality. She's a Research Associate at the University of Glasgow and she's also the project manager of the Newton Bhabha LIGO U.K. - India effort.

Dr. Dimitra Fimi is the co-writer of the book. She's a Senior Lecturer at the University of Glasgow in Fantasy and Children's Literature, and specialist on J.R.R. Tolkien and fantasy literature.

With the help of our colleagues in the LIGO India EPO team, particularly, Samir Dhurde, Manasa Thirugnanasambandam and Shivani Pethe we were able to make this book into a reality translated to Marathi. 1000 copies will be distributed to villages near the LIGO India site, in the Hingoli district and introduce children aged 6-8 to STEM subjects and encourage participation with the parents (older sibling/grandparents) to read along with them.