Building on the IUCAA - University of Glasgow (Newton-Bhabha) collaboration towards LIGO India

Monday 7th and Wednesday 9th February 2022

Objective

To bring together key institutions from key R&D institutions as well as Higher educational institutes in both the U.K and India to discuss how to further collaborate and future opportunities for India-U.K R&D aimed at the development of LIGO India and multi-messenger astronomy.

First day: participants: 30 people

1. Overview on related activities to LIGO India.

Overview talk by Giles Hammond:

A detailed description and summary, including the grant aims as well as all the Newton-Bhabha activities achieved from the beginning of the collaboration. This included skills training done through the built and set up of specialised equipment such as Laser stabilisation, distance learning, student exchanges to benefit from working in the various laboratories within the collaboration in the U.K and take the learnt skills back with them. Other activities to name where the various workshops held both in person and online aimed at the students from undergraduate level to master and PhD students, such as the build-a-detector workshop where students where taught an overview of gravitational wave science crucial for theoretically designing (on paper) their own gravitational wave (GW) detector. The entrepreneurial activities were also highlighted and examples of current gravitational wave spinoffs were mentioned. Finally a roadmap for India-UK future relations was discussed.

2. Indian academic institutes in LIGO India and discussion

IUCAA (Inter University Centre for Astronomy and Astrophysics) presentation by Prof. Sukanta Bose and Prof. Somak Raychaudhury. To provide an overview of the academic programme, support and training of LIGO India personnel

Following the overview talk, members of IUCAA (Prof. Somak Raychaudhury, Prof. Sukanta Bose, gave a joint talk on the current status of LIGO -India as well as the main activities ongoing at IUCAA.

An overview was given on the LIGO-India pre project and IUCAA's role in executing crucial activities to ensure the operation of LIGO India, such as Human Resource Development (HRD), computing and Education & Public Outreach (EPO), IUCAA will also be preparing to un the observatory in the operation and management phase following installation and commissioning in the first phase. IUCAA is currently supporting site activities, training commissioners and operators as well as working to coordinate technological development

and capacity building research, data analysis and computing, and education and public outreach. There was also an overview of the training modules for LIGO-India commissioning at IUCAA which includes seismic isolation, suspension damping, etc. As well as highlighting LIGO-India training and capacity development and R&D projects across the LIGO-India involved institutes

Project	Institute
Expt. Training Program	LI Inst., IISER Pune, SPPU+
Fibre lasers + mode cleaner	IITM, CGCRI (new)
Advanced Control Systems	IITM, IITB, IITD, IIT Dharwad
Wind Resistant Design	BITS-Pilani-Hyd, IIT-Hyd
Acoustic Damping - Metamaterials	IITM, IITH
Multilayer coatings	TIFR-H
Optical Lever	IITM, IUCAA
Squeezer (free space + waveguide)	IISER, IITM
Detector characterization	IUCAA
Data Analysis, Numerical Relativity	IUCAA, LISC

- *Main activities for IUCAA*:

IUCAA:

- HRD, computing and EPO
- Preparing to run the observatory (Operations and Management) once installation and commission is done.
- Currently: training commissioners and operators with LIGO labs in US and RRCAT IPR.
- In charge of coordinating technology, development and capacity building research and activities across the LIGO India institutions.
- Data and computing
- EPO

In the next 5 years:

- Academic training in GW both experimental and theory
- Infrastructure development for GW physics across India
- Technology development for A+ for LIGO India
- R&D for next gen detectors
- EPO work

TIFR presentation by Prof. Karthik Raman. To provide an overview on coating development and mechanical loss measurement at Hyderabad

Prof. Karthik V. Raman gave an overview talk on the work being done by TIFR Hyderabad, describing the Q measurement set up and the coating system were both academics and PhD students are actively working.

Thanks to collaborative work with the University of Strathclyde, TIFR have some coatings substrates to be tested and are now currently assembling our system. They have a cluster of vacuum systems which allows them to use different kinds of material and different techniques (MBE/Sputtering) Several of the pieces are built either in house or locally in India. They have also been developing in house cryogenics, developing activities for setting up a cryogenic cryostat set up.

More specific to LIGO India, they have been working with the University of Glasgow and Strathclyde, starting with PhD student Satyjaki visiting the University of Strathclyde where he learnt about mechanical loss measurements and helped build up a system which was later shipped to TIFR. Two samples were received from RRCAT of monocrystalline AlGaAs DBR (distributed Bragg reflector) mirror to be measured in the mechanical loss system. At TIFR there is also a vacuum chamber with ECR gun which now allows for four targets to be used on a radial turret. Plans for expanding the coating centre at TIFR Hyderabad are in place which will allow the development of a coating centre on campus, allowing for R&D in coating for LIGO facility as well as helping facilitate partnerships with industry and future start ups and research and development for non LIGO activities.

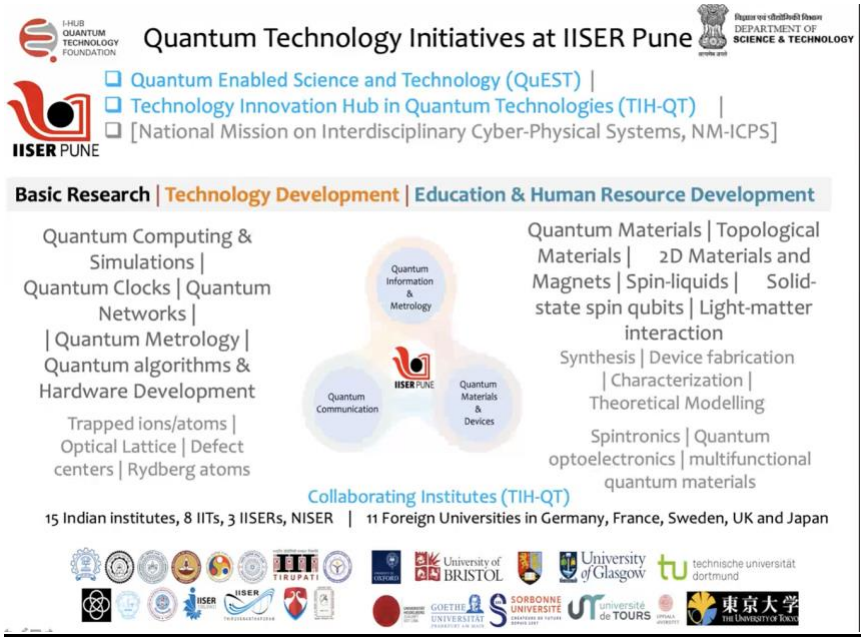
- Condensed Matter Laboratory
- Mechanical Loss measurement setup
- Expansion of the Coating Centre at TIFR Hyderabad

IUCAA is also considering to build a characterization facility and need to discuss with Strathclyde on future of coatings.

IISER presentation by Umakant Rapol (IISER). To provide an overview on laser stabilisation and linkage to Indian Quantum Technology programme.

An overview of the activities at the CGPA (Centre for Gravitational Physics & Astronomy) lab in IISER was given as well as identifying the members involved in the work both in India and in the U.K. One of the key highlights given was to do with how to move forward and the activities that are needed for LIGO India. Looking into the future, how to take the project forward a lot of the technology for LIGO India has an overlap in quantum technologies, going forward there will be a national mission that will come up on quantum technologies, this will be a great opportunity for IISER as there is great synergy between the two projects.

Two Quantum technology initiatives are currently ongoing in ISSER Pune, the quantum enabled science and technology (QuEST) and the Technology Innovation Hub in Quantum technologies (TIH-HQ) where many technologies are being developed such as quantum computing and simulations, quantum clocks, quantum metrology, etc.



Plans for their CGPA lab are ongoing, with the following experimental setups proposed:

- Michelson interferometry fixed and suspension mirrors in vacuum and atmosphere
- Laser stabilization and optical resonator experiments
- Noise analysis
- Vacuum technology
- PMC cavity construction
- Replicating Q-measurement system
- develop broadband squeezer.

Quantum technology initiatives at ISSER Pune are currently ongoing. Atomic clocks building in both ICUAA and IISER which will help develop technologies for LIGO India as well as building gravimeters which will be needed for LIGO India.

There are opportunities for postdocs/PhD students and masters for R&D.

IIT Madras presentation by Roselyn Jose. To provide an overview on control system activities at IIT Madras

Review on work happening for Control at LIGO. Research work on Developing modern control techniques such as reinforcement learning based control for mitigating noise present at LIGO, specifically Newtonian and Seismic noise related. Broadband Newtonian noise cancellation and local damping suspension control have been two of the main problems currently being worked on.

Working on Newtonian noise cancellation using suspension models to test results.

Suresh Doravari pointed out that IUCAA has a suspension training model and they are in discussions with IIT Madras so they can use the facilities for their analysis. A collaboration would be useful to consider here.

3. Development of R&D towards LIGO India and discussion

DCSEM (Directorate of Construction, Services and Estate Management) /IPR (Insititute for Plasma Research) /RRCAT (Raja Ramannan Centre for Advanced Technologies) related activities in LIGO India presentation by Dr Sendhil Raja (RRCAT) To provide an overview of the activities in DAE Institutes (DCSEM, IPR, RRCAT)

LIGO India is a Mega science project and the leading institutes are DCSEM, RRCAT, IPR, with IUCAA leading on the academic side. DCSEM handles land acquisition and they have been very proactive in acquiring the site for LIGO India. IPR focuses on plasma research, plasma technology and high and ultra-high vacuum. They are responsible for the vacuum system in LIGO India. RRCAT – laser centre for light, is focusing now on LIGO India hardware development such as suspensions and setting up a 10 m prototype. DCSEM are responsible for site acquisition and building infrastructure.

LIGO India brief overview – Four lead institutes – IUCAA, DCSEM, IPR and RRCAT. There will be a network of detectors, LIGO Livingston, LIGO Hanford and soon LIGO- India. It is important to have the largest possible baseline to have comparable sensitivity to the LIGO US detectors, and LIGO India will allow better sky-localization of gravitational wave sources by triangulation.

With multi messenger astronomy, localization becomes very important as the sensitivity of the detectors improves, the faster the localization occurs the faster its observation counterpart can be done. One of the main motivations to get this project as early as possible.

GW detector activity in RRCAT – there was a proposal in 1990 to build a 100m prototype put forward but unfortunately wasn't funded. Similarly in 1995, a collaboration with ACIFA was made to participate to build a km GW detector in Perth but again it wasn't funded. Finally in 2009, IndiGO, the India consortium was funded and RRCAT was invited to join.

An MOU was signed in 2016 with DAE on the funding side in India and the NSF in the USA in the presence of the Honourable prime minister of India.

Currently the following activities have been done. In 2016 the approval for the project was given, following this a joint oversight group was set up between DAE_DST and NSF, By Sept 2016 two sites had been identified. Currently the site has been completely acquired, the environmental clearance for the project has been received by the government and other required surveys such as the soil sampling have been completed. A weather and seismic station is established at sire for continuous data acquisition and the site office building is currently under construction (almost completed) at the LIGO-India Observatory site.

Other key points that were listed:

- Vacuum system development, cryo pumps are slightly delayed.
- Outgassing measurement set up for steel coupons (for qualifying the steel).
- BSC Vacuum chamber prototypes (design and fabrication by Indian vendors).
- HAM and BSC chambers have been fabricated and delivered to RRCAT for detector installation training purposes.
- Working on a 10m protype testing and training facility. UHV vacuum envelope fabrication is currently underway with the aim of a summer completion.
- Also working on detectors control training for the 10 m.

In the near future:

- Vacuum system components for LIGO India.
- Four pass laser pre amplifier.
- Fibre pulling set ups for fused silica suspensions.
- Ear tab hydroxide-catalysis bonding for optics (on going).
- Optics development.
- Coating developing is limited in India especially for the low scatter optics.
- Also looking ahead for A+ and Voyager.
- Project dragonfly (An array of 0.5 m fixed telescopes along two arms of the LIGO-India detector with field of view stitching to generate a composite high resolution picture for kilonova detection).

Second day (25 participants)

4. STFC facilities and potential collaborations

Presentation by John Collier (Central Laser Facility) to provide a UK focus on high power laser development, work towards EPIC and opportunities for collaboration with LIGO India.

Long standing relationship / decades of scientific collaboration between India and U.K relation. Started with a Newton-Bhabha award with a number of workshops in the UK and India exploring the potential laser-driven sourced for therapy, diagnosis and biomedical imaging. Leading to a pilot program (funded) between the Central Laser facility (CLF) and TIFR in 2017 for a joint development of control systems for next generation high power lasers.

An opportunity arose to apply for funding for a 5 year program for a £4.03M between UK and India. Plan was to recruit a set of people (20-25) based in Hyderabad, (scientist/engineers) in 2019, with an event in Mumbai and the UK providing training. Training was delayed due to COVID but has now stabilised. The scientific interest in high power lasers, interested in the secondary radiation produced which has unique, non-conventional properties. Proof of principle experiments over last few years, some imaging ones, this are some of the main application areas which can be difficult conventionally such as destroying composites/batteries, etc. These experiments show their innovation potential in biological and industrial imaging. We are also focusing on EPIC (Extreme Photonics Innovation Centre)

to increase the repetition of the laser from tens of minutes to ten times a second, in order to increase the flux over a given period.

UK has invested in a brand-new centre to support this type of application called EPAC (Extreme Photonics Application centre), a £82M investment for a centre for development and applications for laser driven accelerators and sources in academia, industry etc.

There is another facility called SCAPA at the University of Strathclyde which has similar plans for application. And there will be another facility in TIFR Hyderabad, TRISHUL, in a few year time (recently announced by the DAE chairman). The creation for EPIC is to be supportive, key areas that EPIC will be working on will be:

- High Rep-rate targetry/plasma mirrors/target positioning systems.
- High rep-rate particle and radiation detectors
- Control system solutions for laser-driven accelerators.
- Design and manufacture of key opto-mechanics, vacuum systems and EMP resistant drive systems.
- High volume data analysis packages including CT.

The EPIC model could be a model for future collaborations from both the UK and Indian side was that it was a quick way to get established, progressing things at a good speed. There's a clear bilateral benefit. The collaboration has also expanded beyond the initial partners. In terms of LIGO-India specifics for CLF/EPIC, there could be potential interest in precision opto mechanics, automated control. Vacuum infrastructures and data management.

Presentation by Ewan Fitzsimons (ATC) to provide an overview of the Astronomy Technology Centre capabilities, work towards LISA, and expertise in astronomical instrumentation.

Overview of the UKATC (UK Astronomy Technology centre), the UK's national laboratory for astronomical instrumentation, including the Higgs Centre for innovations as well as the ROW Visitor centre. UKATC is part of STFC, which funds astronomy facilities, R&D. There are about 100 staff members at UKATC across all expertise and all aspects of astronomy, 80% of programme at UKATC is astronomy with 20% of non astronomy project such as Earth observation and healthcare.

UKTAC has been involved in the James Webb telescope, ALMA, VLT and ELT as well as LISA. Some of the instrumentation programs currently running at UKATC:

- VLT Moons: UK-led 3rd gen instrument for ESO's VLT with UKATC leading main AIVT, optics, structure, cryogenics, fibres, software and more. Focal plane is also being integrated at UKTAC.
- ELT: HARMONI: UK-led first-light ELT instrument. UKATC leading and contributing with project management, system engineering, overall instrument assembly, integration and testing. Optical and mechanical design such as cryostat, static structure and adaptive optics.

UKATC is also involved in the development of 4 out of 5 of the instruments for ELT (but are lead on the HARMONI)

UKATC also works on software tools for observational programs. SKAO – Observatory monitoring & Control, leading in operator controls and observer tools. UKARC software group also led the development of the observer tools for ALMA.

- VLT Cubes - UKATC is leading and contributing to the optical design, detector sub-systems and science case for getting it off the ground.
- LISA - Lead the UK contribution to the LISA instrument (in partnership with the University of Glasgow) for the design, development, integration and testing of the optical bench interferometer with Phase A (preliminary phase) just completed and Phase B starting this month (April)

5. Coating/laser development in India (TIFR) and discussion

Presentation by M. Krishnamurthy (TIFR) to provide an overview of Extreme Photonics Innovation Centre (EPIC) project, which is a UK-India initiative and a potential model for LIGO India activities.

EPIC is the Extreme Photonics Innovation Centre, at the Petawatt and beyond. The science involved in the innovation centre is intense laser driven science, which is nonintuitive physics and follows integration of optical, plasma, nuclear astronomy and particle physics.

TIFR has been doing this kind of science for the last ~14 years, building small laser that could manage to get in the labs in Bombay. There are also established collaboration with IPR, IIT in Hyderabad, IIT Madras, IIT Joghupur and Hyderabad central University.

The kind of science done in TIFR is slightly smaller than that done in the U.K. However, TIFR have a unique set up/ environment to study all the different states of matter in the same laboratory using the same laser (Atoms/molecules, Micro droplets , Solid slab, nano clusters)

Advanced light sources are large national facilities such as the Diamond synchrotron at Rutherford Appleton Laboratory (UK) and SACLA XFEL in Japan. A key issue is whether high power systems can be made much more compact.

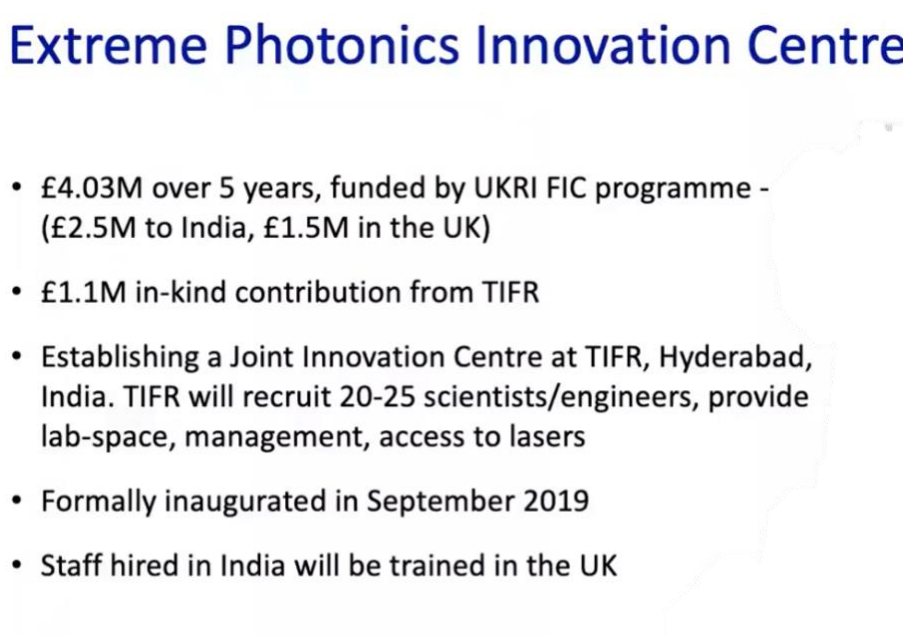
Laser driven sources could provide an alternative to making these compact and usable. Commercial microfocus based scanners tend to be limited by electro beam size as well as the X-ray flux limited by melting of electron beam anode. Another disadvantage is that these tend to be fixed large divergence angle. As a consequence there is a resolution/acquisition speed trade off, they are not easily tunable and objects cannot be imaged at a distance.

Some of the industrial imaging challenges EPIC would like to work on are:

Imaging low density materials at high resolution, imaging large dense objects at high resolution in 3D, imaging dynamics. There is also a need for advanced imaging sources (high flux, high-resolution, compact) and multi-modal imaging for complementary information.

This joint research project between CLF collaboration under the Newton-Bhabha program started in 2012 (before the MoU was signed in 2014). The idea was to involve fundamental science, potential for translational research and create capacity for building in associate science and technology. Starting with modest funding from the U.K for 5 years, this included visits and consumables for experiments as well as in-kind funding from TIFR. At the end of this 5 year program there was a joint meeting to see how to move forward, and the idea of bringing an innovation centre to jointly develop laser technologies. A year later the resources were identified and in 2017 a new project focussed on cutting age technologies was developed between CLF and TIFR. This included a 100K GBP a year, with the goal to develop control systems for laser based accelerators. It includes 4 engineers trained in EPICS and deploy projects to control different elements of laser manipulation and diagnostics.

During these two year period of diagnostic the innovation centre was set up and EPIC was funded.



A workshop to define common areas of interest was arranged in Jan 2020 with 40 participants from different backgrounds such as laser, astro-physics, etc and 4 topics where identified of interest; Targetry, detector and diagnostics, control systems and engineering.

For both India and the U.K to porgress this at amore ambitious level which has started in the UK with EPAC and TIFR with TRISHUL which will be done in a few years. The science done here will invite industry and allow for cross relations between industry and academic R&D.

6. Multi-messenger follow up in India (GROWTH telescope, IIT Bombay) and discussion

Presentation by Varun Bhalerao (IIT Bombay) to provide an overview of some of the rapid follow-up required for LIGO India and the development of the GROWTH robotic telescope.

An overview was given on the GW170817 neutron star binary which emitted in both electromagnetic and gravitational waves. Lessons where learnt in Observing Run 3 of LIGO including the need to keep an eye on the sky at all time and the need for increased sensitivity and rapid deep optical follow-up. Finally one needs to get enough information to characterise and interpret the source. These are the goals for Daksha, two satellites with three types of detectors, covering low energy, medium energy and high energy.

Daksha: key statistics -

- Broadband energy coverage 1kEV to > 1 MeV
- Median effective are: 1300 cm^2
- Sky coverage: 1 satellite ~ 50%, two ~87%.

- Event alert within ~1 minute
- Downlink all event mode data – offline searched would be possible.

Looking at the models Daksha would have a bigger range than for example Fermi, about 3-10 x better range than Fermi and Swift. This would mean an increase in subthreshold events and in return increase LIGO rates. Daksha will also be able to do Gamma-ray burst, excellent capabilities to do GRV polarisation, only mission that will be able to do prompt soft spectroscopy, high redshift GRBs and fine time resolved spectroscopy. As well as TGFs, XRFs, solar flares, pulsars, etc.

The mission is not fully funded / approved yet. And will hopefully have the international community involvement.

7. Discussion session to reflect on the two day workshop and next steps

Discussions overview:

An open discussion was then held in order to discuss specific details from the two-day workshop and plan future actions. Key points raised included;

- There is significant benefit in showing in-kind contribution for both UK/Indian funds. This has worked well for Newton-Bhabha funding
- 10 m protypes are scarce but having one in RRCAT where we can do fast turn around is the gateway to longer baseline instrumentation and an important development aspect
- IUCAA wants to be involve in both observatory and R&D tasks. Re attracting talent back to India. Need to look at possible Indian fellowship opportunities
- India / UK relationship key to make connections. This should ideally be done at scientific, funding agency and British consulate/embassy.
- The Indian government is keen to support industry /academic collaborations and local technology innovation.
- Many opportunities for links and spin offs which may be interesting to promote gravitational wave activities.
- Identify potential industries in India to make contact or collaborations with LIGO India since a lot of the partnerships are not in place.
- Many technologies will be of interest to other industries in India since they will be brand new technologies.
- RRCAT is keen to develop future activities that could lead to a cryogenic 10m, although LIGO India is the primary focus. This links to UK activities in this area

- **Key action points to take forward**

1. To explore a program to engage with local students at the different levels to encourage participation and possible future enrolment in programs that would lead to master/PhD and post docs to work on LIGO India. Professional development beyond the initial student training so they can lead the various work packages within the projects in India but also to help establish capabilities for building LIGO India. **IUCAA/Glasgow to initiate.**
2. There is an interest in further discussing specific research opportunities which could form the basis of a future bid. Possible areas include (i) a future mirror coating centre in India (ii) the development of technology for wide deep-field telescope. These will be explored via a pair of workshops dedicated to the topics. **Glasgow to initiate**.
3. Explore ways in which LIGO India and the UK can work with the British Consulate to highlight the work of LIGO India. **Glasgow to initiate.**