LIGO-India

An Indian Mega-Project for Gravitational-Wave Science

Tarun Souradeep

Many scientists from India have been working in the area of gravitaional wave detection as part of the LIGO international collaboration. This article recounts how these smaller scale efforts grew into a proposal for locating an advanced detector in India, which brings very significant scientific advantages. There is now in-principle approval for funding the Indian contribution to building such a facility. The article brings out the opportunities as well as major challenges which now open up to a much wider community of young scientists and engineers, in building and running such a unique laboratory.

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The Indian Union Cabinet's in-principle approval on Feb 17, 2016, that brought the gestating LIGO-India mega-science proposal to life, has swiftly followed the historic announcement on Feb 11, 2016, of the first detection of a gravitational wave (GW) event by Laser Interferometer Gravitational-Wave Observatory (LIGO), USA. This formally embarks a set of detemined scientists of the pan-Indian IndIGO consortiumand the LIGO-India teams on a fantastic adventure in a blossoming big-science frontier. What lies ahead for LIGO-India is a tough and challenging path of multi-institutional scientific collaboration together with major industries in India to build an advanced Laser Interferometer Gravitational-Wave Observatory on Indian soil over the next 8 years and then operate it at its design sensitivity[1] for the next decade, or two. Many of the young science and technology enthusiasts reading this article would have, before then, attained sufficient learning and training to allow them to join in this amazing adventure in India. This is, especially, a note of welcome for them.

[1] Design sensitivity refers to the weakest signal which can be detected in the presence of various disturbances. Achieving this requires fine tuning of all the optical, electronic, and mechanical systems over months or even years to remove all undesired sources of 'noise'.

Keywords
Gravitational waves, advanced detector, Indian project.

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dark, or shrouded, core of astrophysical phenomena in the universe, and also allows an experimental probe of gravitation theory in extreme situations such as two black holes merging. The weakness of interaction of GW with matter that has made them so difficult to detect till recently, allows them to emerge unscathed from the very core of violent astrophysical phenomena such as a supernova explosion, gamma-ray burst from coalescing neurons stars or an invisible merger of black holes. In contrast, in dense, hot environments, such as the interior of our Sun or at the core of energetic phenomena, electromagnetic radiation is strongly scattered within the dense material and it is only possible to map the exterior boundary, generally referred to as the photosphere. GW astronomy is, hence, privy to details not accessible to astronomy using the entire spectrum of electromagnetic waves, ranging from radio waves to X-rays and gamma rays, all of which can map only up to a dense photosphere enshrouding the central engine of energetic phenomena. The central energy source is a deep gravitational potential well into which matter falls at relativistic speeds, and Newtonian gravity must be replaced by general relativity. This gives rise to new physical phenomena which gravitational waves will allow us to probe, no doubt bringing out new surprises.

Few years into the millennium, during the phase of operation with the Initial LIGO detectors in USA and its close cousin, VIRGO, in Italy, concrete designs of the advanced interferometer detectors achievable in a decade were being drawn up. The advanced generation of GW detectors indicated a ten-fold improvement in sensitivity. That meant a thousand-fold increase in the expected rate of cosmic events that would produce detectable GW signals on Earth, implying at least one event per year even in fairly pessimistic astrophysical scenarios. It was eminently clear that the detection of GW signal from astrophysical phenomena, in particular, merger of compact neutron stars and black-hole binaries, was guaranteed with Advanced LIGO.

The recent detection of GW presents a vast opportunity over the coming decades for furthering the frontiers of astronomy with a global network of observatories, followed by GW observatories in space. The larger the baseline, the more refined is the inferred location of any GW event; hence, there was a call for establishing additional GW observatories across the globe.

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A few researchers in India recognised the great opportunity it provided to the Indian scientific community. They started to plan and prepare a decade in advance to welcome the emerging field as equal partners at the global frontier. In a radical departure from the norm, Indian scientists would then be well entrenched in an emergent frontier field well before it had blossomed and gone out of reach.

India responded fairly early with the first serious discussion taking place in late 2007 at the International Conference in Gravitation and Cosmology (ICGC) in IUCAA. In August 2009, at another meeting in IUCAA, a consortium of Indian researchers called IndIGO, that collectively had expertise in theoretical and experimental gravity, cosmology and optical metrology, was formed. This consortium sought to promote gravitational wave research in the country with a dream of realizing an advanced GW observatory in India. This multi-institutional, multi-disciplinary IndIGO consortium now consists of three lead institutions for LIGO-India and nine other nodal institutions. Starting from 14 members in 2010 it has grown to 120 members today. With 3 experimenters then, it has 56 experimenters today. The Indian membership in the LIGO Science Collaboration, from a single group at IUCAA during 2000–2010, has now grown to a pan-India group with 61 members, including 21 experimenters, from nine Indian institutions, namely, IPR, IUCAA, RRCAT, TIFR, ICTS-TIFR, CMI, IIT-Gandhinagar, IISER-Kolkata, and IISER-Thiruvananthapuram.

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The Initial LIGO consisted of two observatories: one with two interferometer detectors at Hanford, Washington State and the other with one detector at Livingston in Louisiana. While all three detectors were upgraded in the Advanced LIGO project funded by NSF, it was clear that only a geographical relocation of the second Hanford detector to a globally distant location would enable the LIGO laboratories to translate the detection of GW events into a discipline of GW astronomy. The initial destination for the third distant LIGO was Australia.

Invited to the membership of the Gravitational Wave International Committee (GWIC), IndIGO explored the Indian contribution to the International Advanced GW Network. It planned for the participation in LIGO-Australia with 20 per cent contribution. When it seemed that funding for LIGO-Australia may not be forthcoming from the Australian government, in mid 2011, preliminary discussions for locating to India (i.e., LIGO-India) were initiated. With strong encouragement from Indian science luminaries, the LIGO-India proposal was put forward by IndIGO to the mega-science committee of the Indian Planning Commision in November 2011.

The LIGO-India proposal is for the construction and operation (for 10 years) of an Advanced LIGO observatory in India in collaboration with the LIGO Laboratories, USA. With design displacement sensitivity of 4×10^{-20} m the LIGO detectors are the most precise physics apparatus. *Figure* 1 shows the layout of this enormous scientific apparatus. The 4 km beam tube along each arm holding about 10 million litres of ultra-high vacuum (nano-torr[2]) would make it an impressive tribute to technological prowess of Indian science and technology. LIGO-India is expected to improve greatly the angular resolution in the location of the gravitational-wave source by the LIGO global network. Indeed, a

[2] For comparison, the sizes of atomic nuclei are measured in units of 10^{-15} metres. A nano-torr is roughly one millionth of one millionth of atmospheric pressure.

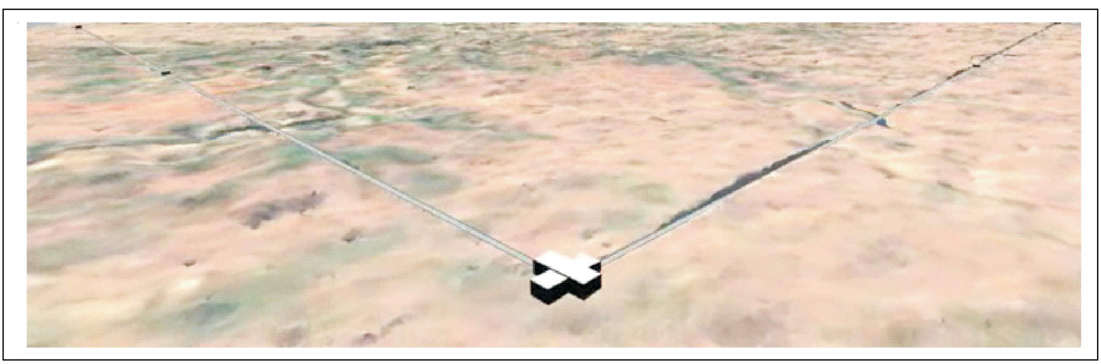

Figure 1. Engineering concept design of LIGO-India at one of the shortlisted sites in India. Terrain data obtained from CartoSat, SAC, ISRO. Courtesy : TCE, India.

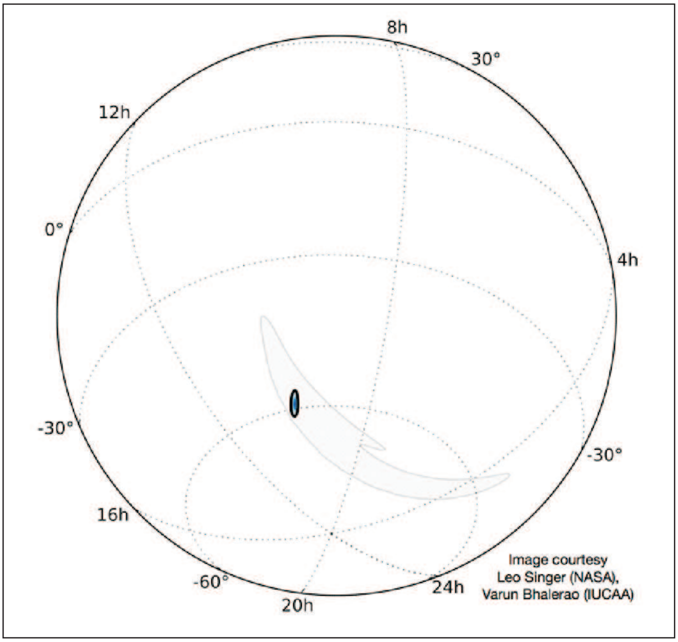

Figure 2. The immense promise of LIGO-India in enabling localisation of gravitational-wave events in the sky and launching gravitational wave astronomy. The grey banana-shaped patch spanning 2500 moons is the current uncertainty of the localisation of the first discovery event. The small dark ellipse that is 100 times smaller shows the forecast uncertainty for a similar gravitational wave signal when LIGO-India is operational.

startling attestation to the promise of LIGO-India comes from the forecast that, for the specific event detected, in Sept 2015 by the two Advanced LIGO detectors, a hypothetical LIGO-India in operation would have made a hundred-fold improvement in the angular resolution as shown in *Figure* 2.

The construction, commissioning and the scientific operations of the planned LIGO-India observatory will involve three Indian lead institutions, the Institute for Plasma Research (IPR), Gandhinagar, the Inter-University Centre for Astronomy and Astrophysics (IUCAA), Pune, and the Raja Ramanna Centre for Advanced Technology (RRCAT), Indore, working in close collaboration with LIGO Laboratories, USA. Broader Indian participation in this mega-science initiative will be made possible through the IndIGO consortium.The entire hardware components of the third advanced LIGO interferometer that have been already manufactured by USA UK, Germany and Australian partners are to be provided to India by LIGO, USA.The entire infrastructure including the two 4 km ultra-high vacuum (UHV) beam tubes and its controls, as well as the team to set up the interferometer and operate the observatory will be the Indian

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responsibility. The LIGO Lab USA is committed to share and provide detailed designs and documentation of all aspects of the LIGO detector. It would also assist during installation, commissioning and noise-limited operation at the LIGO-India site.

LIGO-India teams at IUCAA, IPR, RRCAT have been at work even in the pre-approval phase. The site-selection committee at IUCAA has looked at over 22 sites and worked to shortlist a few of them based on site-selection criteria like low 'seismicity' (ground noise), low human generated noise, socio-environmental considerations of land acquisition, air connectivity, road connectivity and data connectivity. IUCAA has also started science team-building activity and has been steadily building up a state-of-the-art computing, data infrastructure and associated manpower in anticipation of LIGO-India. The team at IPR has prepared system requirement documents, conceptual drawings and engineering drawings for the sophisticated civil infrastructure, and ultra-high vacuum systems in consultation with LIGO Labs. The team at RRCAT has been finalizing plans for setting up an off-site laboratory to receive the laser systems, and optics for LIGO-India. Pre-approval preparations have included many schools and workshops at different levels and also selection of Indian UG students for summer internships at LIGO USA and other top GW research centres worldwide. With the approval from the Union Cabinet, the combined LIGO-India team is now in a high state of readiness to take the first steps which have already been planned.

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The discovery and the approval of LIGO-India paves the road to the possibility of observing our universe using gravitational waves as the messengers carrying information. The IndIGO consortium has also seen increasing participation from the Indian astronomy community in anticipation of this new emerging frontier of 'electromagnetic follow-up' of GW events. Indian facilities such as AstroSat launched by ISRO, and GMRT near Pune, and Himalayan Chandra Telescope in Hanle, Ladakh would engage in this effort.

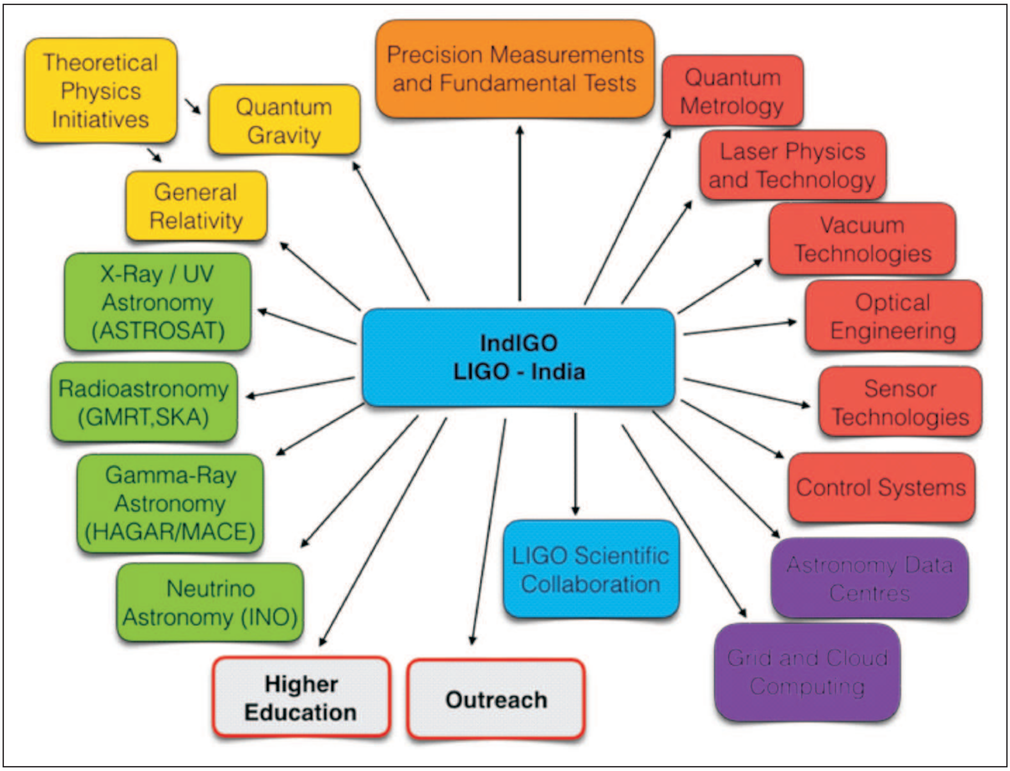

Figure 3. The impact of LIGO-India is multi-faceted and would push the frontiers along each direction. (LIGO-India proposal document Nov 2011.)

LIGO-India has the potential to impact precision experiments and cutting-edge technology in the country. The project has interfaces with quantum metrology, laser physics and technology, vacuum technologies, optical engineering, sensor technologies, control systems, grid and cloud computing to list a few. *Figure* 3 adapted from the LIGO-India proposal depicts the multifaceted impact of this project. LIGO-India has been a dream nurtured and sustained by wonderful courageous colleagues in India. IndIGO looks forward to enthusiastic participation by a generation of young scientists and engineers in this adventure of exploring the sky using the latest probe – gravitational waves.

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