TIFR ALUMNI ASSOCIATION

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TAA requests its members to update their email ID by sending a mail to alumni@tifr.res.in or tifraa@gmail.com

About TIFR Alumni Association

The idea of forming the TIFR Alumni Association was first conceived by a few of its members at a meeting held on December 24, 1999. The alumni now has a membership of approximately 570 past members. However, this is just the tip of the iceberg. There are several members spread across the country and also in other countries who have been actively associated with TIFR in the past. Our aim is to tap this rich pool of ex-TIFR staff so as to create an integrated resource of people with expertise in different areas of sciences.

Apart from its outreach efforts, TAA has been actively cooperating with the Institute to raise awareness about the need for a vibrant endowment fund. With support from philanthropists and corporate entities, TAA has managed to contribute to the TIFR Endowment Fund and instituted Best Thesis Awards and awards in specific fields. The Aveek Guha Memorial Lecture is the latest endowment received through the TAA. These efforts will continue, and we seek the active cooperation of all well-wishers of TIFR in this endeavour.

Alumni Activities

Awards nucleated by TAA

Prof. Ramnath Cowsik, an alumni of TIFR, endowed two medals in the year 2011. The medals are to be awarded to a member of TIFR - visiting, regular or otherwise - for his/her contribution to an outstanding paper in any field published in the three years prior to the award. The awardees for the year 2016 are:

Shri Ramakrishna Cowsik Medal ***to Dr. Ramya Purkanti***

Smt. Saraswathi Cowsik Medal ***to Dr. Tanvi Deora***

TAA Excellence Award

Prof. Prahlad Chandra Agrawal

Prof. Spenta Rustom Wadia

Prof. Nallagounder Periasamy

TAA Patent Award

Prof. Gayatri Venkiteswaran

Prof. Saikat Chakraborty

Dr. Souvik Mody

TAA Excellence in Teaching Award

Prof. V. Srinivas

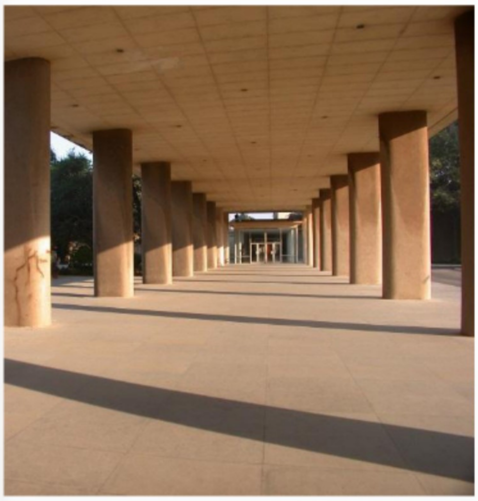
Prof. Sudipta Maiti

TAA extends its heartiest congratulations to all the awardees.

Future planned events:

Aveek Guha Memorial Lecture – a new initiative – is scheduled sometime in October 2017.

Images@TIFR



Images: courtesy TIFR Photography

In Memorium - *Prof. K. Chandrasekharan - November 21, 1920 – April 13, 2017*

Komaravolu Chandrasekharan, one of the leading Indian mathematicians of the twentieth century, passed away on April 13, 2017 at the age of 96 in Zurich Switzerland. KC as he was known to many, was a well-known figure in the scientific community in India during the fifties and sixties. This was the time when he headed the School of Mathematics at the Tata Institute of Fundamental Research (TIFR) in Mumbai (then Bombay); and under his stewardship (TIFR) in Mumbai (then Bombay); and under his stewardship that school grew from the fledgling that it was in 1950 into a world-renowned centre for mathematics (that it continues to be today), all in the short pace of a decade and a half. He left India in 1965 to take up a professorship in Zurich, Switzerland, and with that he has been virtually forgotten in this country despite his immense contribution to the organization and promotion of mathematics (and science) in India during his TIFR years.

Chandrasekharan was born in 1920 in Machilipattanam in Andhra on November 20, 1920. His father was the Headmaster of a school in the small town of Bapatla (also in Andhra Pradesh). He had his early education in Bapatla in Andhra Pradesh. He moved to Chennai (then Madras) for higher studies and obtained his B A (Hons) degree in mathematics in 1943 from the University of Madras through Presidency College. He then went on to pursue a PhD degree under the guidance of Professor Ananda Rau (a leading mathematician of the time) even as he worked as a part-time lecturer in Presidency College and was awarded that degree in 1946. Marshall Stone, a leading American mathematician was visiting Madras - he was drawn to that city because of his interest in Indian music - met Chndrasekharan there and was impressed enough with the young man to arrange for him to go to the Institute for Advanced Study (IAS) in Princeton to work as Assistant to the famous mathematician-physicist Hermann Weyl - IAS, a Mecca for the mathematicians, is the institute where Einstein was a permanent professor (as was Weyl).

Homi Bhabha on a visit to the US (essentially for the purpose of recruiting faculty for TIFR) met him in Princeton and offered him a position at TIFR. KC accepted the offer and joined TIFR as a Reader in July 1949. At the time of his joining TIFR, there were only two other mathematicians in the institute: F W Levy and D D Kosambi. Levy had fled Nazi Germany and was a professor at the University of Kolkota when Bhabha recruited him. Kosambi was at the Banares Hindu University before moving to TIFR and around the time KC joined TIFR he was moving away from mathematics to historical research. Chandrasekharan rose rapidly in the ranks and he was appointed Deputy Director (Mathematics) in 1960. He was instrumental in restructuring TIFR to have two schools – the School of Mathematics and the School of Physics with functional autonomy in all academic matters in the respective fields and was the (first) Dean of the School of Mathematics.

Chandrasekharans mathematical researches were in the area of classical analysis (much of it in Summability) and Number Theory. There seems to be a revival in recent years of some interest in his papers on Dirichlet Series (written jointly with R Narasimhan) that appeared in the prestigious Annals of Mathematics in the sixties. He was among the finest Indian mathematicians of his generation. He wrote two books both of which were well received. One titled Fourier Transforms had as co-author Salomon Bochner (of the University of Princeton), one of the big names of the twentieth century.

The other, Typical Means was joint work with a fellow Indian, Minakshisundaram. Minakshisundaram was arguably the most gifted Indian mathematician of that generation. KC was the first recipient (in 1959) of the Bhatnagar Prize for Mathematics and was also awarded the Padmashri in the same year.

KC left the Tata Institute of Fundamental Research in 1965 to take up a permanent professorship at the Eidgenossiche Technishe Hochschule (ETH), a premier scientific research institution in Switzerland located in Zurich. But his achievements in the short span of about 16 years that he spent at TIFR, are truly impressive and have few parallels in the Indian scientific scene. After he joined the institute mathematical activity at TIFR grew by leaps and bounds in the next few years, thanks to the diverse initiatives he took. One of these initiatives was the recruiting of K G Ramantahan, a fine mathematician (with interests somewhat removed from those of KC himself). The most important of the initiatives was the creation of a mathematics graduate school broadly along the lines of those in universities in the West, yet differing from them in some ways to suit local (Indian) conditions. The students for admission to the graduate school were selected with great care ensuring that the recruits were highly talented. As mentioned earlier, the German professor left TIFR soon after KC joined and Kosambi showed no great enthusiasm for training students. With just himself and Ramanathan available for teaching, Chandrasekharan embarked on a programme of getting a large number of visiting professors from abroad to give graduate courses to the students he had assembled. With the contacts he had made during his years in Princeton, he was able to persuade many leading mathematicians in Europe and America to visit Mumbai for extended periods of time and give graduate courses. The intellectual fare provided by the visitors ignited the minds of the brilliant students and resulted in outstanding research emanating from TIFR by the late fifties. Two of these visitors who rank among the 20th cetury's greats, C L Siegel and L Schwarz, had a particularly strong influence on the mathematics school. Both of them made several lengthy visits, during every one of which they gave graduate courses.

Chandrasekharan got his wards to take down notes of the graduate courses by the visitors and published them after getting them vetted by the lecturer. TIFR continues this practice to this day except that with its coming of age, the visitors are often there for collaborative research with the local faculty rather than to give graduate courses. These publications (known as the Mathematics Lecture Notes Series of TIFR) have a high reputation and even the ones dating back half a century to Chandrasekharan's time at TIFR, are much sought after even now by the international mathematics community: they have now been digitized and are available for free downloads on the TIFR website.

By the late fifties, the graduate school was producing research work of high calibre and the standards of theses written at TIFR were comparable to those in leading institutions in the world. One major difference between the graduate school at TIFR and those in Western Universities (and this was Bhabha's rather than KC's innovation) was that students were hired as "Research Assistants" on a scale with yearly increments and were members of the Provident Fund after a initial year of probation. They were given 5-year contracts which could be extended indefinitely. The emphasis was on acquisition of wide and deep scholarship; while original research was certainly the prime expectation from the Research Assistants, there was no pressure for publication or even to write a PhD thesis within a stipulated time. Students often registered for a degree well after they had completed the research needed to get the degree. The students who performed well became faculty and placed in a higher scale.

Chandrasekharan responded to good work from students as well as junior faculty with an alacrity not seen in our institutions of higher learning (and in this he had Bhabha's unstinted support and in fact KC was following Bhabha's lead): he promoted them to higher levels - there was no requirement that the candidate should have a PhD. Indeed the bye-laws of the institute ensured that bureaucratic norms will not come in the way of promoting excellence. There was at least one case of a mathematician appointed as Associate Professor without a PhD; and the promotion in fact skipped two grades! The mathematician (C P Ramanujam) had of course some out-standing research publications to his credit and one of them later fetched him the PhD degree. Chandrasekharan set very high standards for research: he was ruthless in weeding out mediocrity even while he was being pro-active in promoting excellence. His assessments of professional perfomance (done in consultation with colleagues and visitors) were by and large fair. However some of the harsh decisions could have perhaps been implemented with greater compassion.

Another important initiative of Chandrasekharan was the organization of a periodic (every four years) meeting which he named "Intenational Colloquium" at TIFR (which cotinues) to this day. This is a closed-door meeting (open however to all TIFR faculty and students) of invited experts from all over the world on a specific topic chosen by the Mathematics Faculty. The main factors that go into this choice are major recent developments in the area and a substantial contribution from TIFR mathematicians. The idea was conceived by KC and he also put in the necessary effort to implement it. He persuaded the International Mathematical Union (IMU) to sponsor these meetings and also got the Dorabji Tata Trust fund them substantially. During his tenure at TIFR, three of these conferences took place and he was the Organizer-in-Chief for all of them. He had a big role in the choice of the theme of the conferences (two of which were somewhat distant from his own interests).

The mathematical genius Srinivasa Ramanujan left behind a whole lot of notebooks in which he had jotted down many mathematical comments and formulas. Chandrasekharan conceived the idea of photocopying the note books (which were in the custody of the University of Madras) and publishing them thereby giving access to the mathematical public to some unpublished ideas of Ramanujan. As was his wont, he pursued the idea to its successful implementation securing the co-operation of the university and obtaining the necessary financial support from the Dorabji Tata Trust.

Chandrasekharan was also responsible for the creation of the Department of Mathematics at the University of Mumbai in 1960 and getting Shrikande, a distinguished mathematician to head it. Till that time, the University functioned largely as an examining body that awarded degrees, the teaching and research in most subjects being carried out in the affiliated institutions.

Homi Bhbha evidently saw in KC lot more than the superlative administrative skills he displayed. Bhabha made him a member of the Scientific Advisory Committee to the Cabinet of which he himself was the Chair. That committee drew up the Science Policy Resolution of the Government of India.

KC is widely believed to have drafted that document. Jawaharlal Nehru set up a committee to write a report on the debacle in the war against China in 1962. KC was a member of the committee and I was told that Bhabha was somewhat unhappy that he did not have advance information on that!

There is a mural by M F Husain that adorns the wall next to the library on the mezzanine floor at TIFR. Husain was commissioned to paint this mural as the winner of a competition. Bhabha had persuaded a number of artists to submit entries for the competition - the entries were scaled down versions of what the artist would paint on the wall if commissioned. The only TIFR member on the jury of four appointed by Bhabha for the competition was Chandrasekharan, an indication of Bhabha's regard for KC as a connoisseur of art (the other three were renowned art critics).

Chandrasekhran was a man of great sophistication and refinement. He was a much admired man in TIFR and second only to Bhabha at that; however he inspired awe rather than affection. He was socially somewhat aloof. There were just a handful of people at TIFR who interacted with him in non-professional ways. At the professional level his conduct was rather formal but impeccable; and he never allowed social acceptability or otherwise to interfere with his enthusiasm for professional excellence in a colleague. He dressed formally - he would turn up at TIFR always in a suit, even in the hottest summer days. Colleagues wanting to meet him had to take an appointment. He spoke (always in English) in a deliberate measured accent which was not British nor American, but would not be recognized as Indian either. Most of us at TIFR formed certain impressions about him though we did not get close to him (we were inclined to believe that no one outside his immediate family ever got really close to him). The way he dressed and the way he conducted himself at the rare official parties suggested to us that he was a stickler for (Western) etiquette who could give a lesson or two to Emily Post!

He counted among his friends many of twentieth century's great mathematicians: Hermann Weyl, John von Neumann, Marshall Stone, Laurent Schwarz, Andre Weil, Carl Ludwig Siegel (whose selected works, he edited), Georges de Rham, Heinz Hopf, Henri Cartan.... to name a few. Henri Cartan came all the way from Paris to Mumbai for the inauguration (by Pandit Jawaharlal Nehru) of the present campus of TIFR (in Navy Nagar, Colaba).Thanks to Chandrasekharan, Hermann Weyl's personal collection of all the volumes of the journal Mathematische Annalen (begining withe the first volume) was bequeathed to TIFR. I have seen a letter written to him by Andre Weil in early 1965. Weil apparently knew that KC was planning to leave TIFR. He writes in that letter to KC suggesting that he should seriously consider taking up the chairmanship of the Mathematics Department at the University of Princeton and seeks his permission to take up the matter with the President of the University (President Goheen was a good friend of Chandraskharan's). KC apparently told Weil that he was not interested in the Princeton job. Switzerlznd of the sixties was far from keen on their prestigious institutions hiring foreign nationals. Georges de Rham (a Swiss) had considerable influence with the Swiss Government of the day and exerted it to get Chandrasekaran to ETH - de Rham evidently had high regard for Chandrasekhran as a mathematician.

TIFR made him an Honorary Fellow of the institute a year after he left, a gesture of recognition of his stature as a mathematician as well as of his contributions to the institute

KC's contributions to the development of mathematics had an international dimension. The International Mathematical Union (IMU) is the oldest of all the international scientific union - it had come into existence at the turn of the last century.

However it was largely a European organization with the US and Canada playing somewhat limited roles. The functioning of the IMU during the period between the two world wars was disrupted because of the souring of relations between the French and German mathematicians. The American mathematician Marshall Stone initiated efforts to revive the IMU in the post second world war world. He formed a committee to draw up revised statutes for the IMU. Chandrasekhran who was roped into the committee by Stone was apparently a major contributor in drafting the new statutes. He went on to serve for a record 24 years on the Executive Committee of the (new) IMU, five of them as Secretary and four as President. During his tenure as Secretary he formulated the rules for the conduct of the International Congress of Mathematicians (ICM), the principal event IMU organizes every four years; and the statutes he laid down in the mid-sixties for its conduct continue to be operative to this day. KC also played a significant role in bringing the Soviet Bloc countries into the IMU fold (during the height of the cold war). He also steered the IMU into taking great interest in promoting mathematical activities in the developing countries. He also served on the International Council of Scientific Unions (ICSU) as Secretary General and at a later point he was also the President.

Chandrasekharan was at ETH till his retirement in 1988 and continued to live in Zurich till his death. While personal considerations were the primary reason for his quitting TIFR, he seems to have had differences with Bhabha on matters of policy which may also have contributed to that decision. I expect that KC remained an Indian citizen until his death: I met him once in Zurich in the year 2000 (that was the last time I met him) when he told me that he was an Indian citizen at that time and that he had no intention of giving up that citizenship

I will end this note recounting some anecdotes: they will perhaps throw more light on his colourful personality than all that I have said above.

I will begin with my own encounters with him. My first encounter was at the entrance interview for TIFR – he was the chair of the committee. He asked me a (mathematical) question and I was struggling with it when he declared "Ah he must have mugged it all up and is unable to reproduce it here!". I was seething with anger but of course dared not show it. That was in fact the only intervention he made during that interview and I went back with the impression that he was a bully.

After I joined the Tata Institute, during the 5 years he was there, I had met and spoken to him exactly thrice. The first experience was to reinforce my first impressions. KC was at that time Secretary of the International Mathematical Union and was responsible for the publication of the "World Directory of Mathematicians" a publication that was essentially a listing of mathematicians (so determined by a specified criterion). KC got some members of the school to help him with this – their job was to go through the list of names provided by the member countries of the IMU and remove names that do not qualify. This was essentially a clerical job but requiring some back-ground in mathematics. It was the general feeling in the school that KC thought none too well of those whom he inducted into this job.

The third story is really hearsay – I do not remember who I got it from. When Bhabha was in Princeton to recruit KC, one day KC was taking a walk with von Neumann and just a little ahead of them Bhabha was walking with Einstein and Yukawa. von Neumann apparently turned to KC and asked him if he was planning to take up Bhabha's offer; when KC responded saying that he was considering it seriously von Nemann told him: "That man is as good a physicist as any, but don't let that intimidate you – stand up to him!". And if any one stood up to Bhabha any time in TIFR, it was KC.

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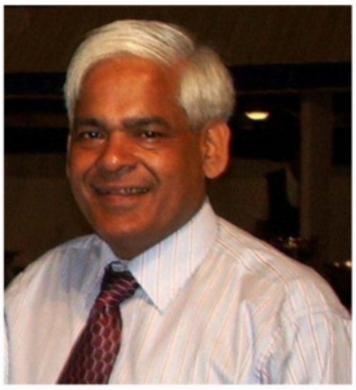
In Memorium - ***Dr. C. S. Jain (- April, 2017)***



Dr. Chandra Shekhar Jain, after completing his doctorate at TIFR, joined Oil and Natural Gas Commission, ONGC, as a Mathematician. He continued to be a torch bearer of the mathematics discipline in ONGC, though it was later discontinued. He was the lone Executive Director, the highest level within ONGC, from mathematics discipline ever.Dr. Jain played pioneering role in introducing the then modern and new field of Numerical Reservoir Simulation in ONGC. He trained generations of reservoir engineers in this important discipline for oil and gas field development. He himself was very competent in conducting simulation studies.

Dr. Jain's entry in ONGC coincided with the initial development of the India's only Giant oil field Mumbai High. Dr. Jain was an authority of Mumbai High. Simulation models constructed by him were in use for decades. His studies were used as a guidance for cumulative investments running in billions of dollars.

He was very unassuming, approachable and popular officer in ONGC. He also helped ONGC build a financially sound self-contributory pension scheme. Because of his enthusiasm for bridge, he built and was part of a formidable team which won several laurels in Public Sector tournaments.

Even after his retirement he was consulted by ONGC in many vital reservoir matters. He utilised his physics insight, mathematical acumen and programming skills in solving applied problems in the oil and gas industry extremely successfully. His example will inspire young researchers in basic science to accept challenges in applied science and industry.

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In Memorium - *Prof. D.P. Roy – (1941 – 2017)*

Professor Durga Prasad Roy, a former member of the Department of Theoretical Physics at the Tata Institute of Fundamental Research (TIFR), Mumbai, India, passed away at his native village in Cuttack, Odisha in the early morning of Friday, March 17, 2017, after a brief illness. He was 76 and is survived by his wife Monica, daughter Kalyani and two grandchildren. In spite of his age, Professor Roy – popularly known as D.P. – had been very active professionally and otherwise, and was in good health and spirits almost till the very last moment. His sudden demise left his family, and many of his colleagues and collaborators in a state of utter shock.

Professor Roy was born in 1941 at a village called Jobra, near the city of Cuttack in Odisha. His initial education was at his native place, after which he graduated with a B.Sc. degree from Ravenshaw College (now University), at Cuttack. He earned his M.Sc. degree at the University of Delhi and was thereafter selected at the TIFR as a doctoral student. Here he worked under the supervision of Prof. B.M. Udgaonkar in the area of particle physics, and received his Ph.D. degree in 1966. Following this, he carried out postdoctoral research at, respectively, the University of California, Riverside (1966-67), the Theory Division of CERN, Geneva (1968-69) and the University of Toronto (1969-70). From 1970 to 1974, he worked at the Rutherford Appeleton Laboratory in the U.K., from where he wrote several interesting papers in the early days of QCD phenomenology. Driven by a passion to improve research at the University level in India, D.P. accepted an invitation from his former teacher S.N. Biswas to join Visva-Bharati, at Santiniketan in India. He taught there for two years (1974-76), after which he accepted a position at his alma mater, TIFR. He joined the Department of Theoretical Physics (Theory Group) at TIFR as a Reader in 1976, and eventually retired from there in 2006 as a Senior Professor, after a research career spanning 30 years, during which he had published many impactful papers in particle physics. However, even after retirement, D.P. did not give up his passion for research and teaching. This motivated him to re-join TIFR in the Homi Bhabha Center of Science Education (HBCSE), on a DAE Raja Ramnana Fellowship (2006 - 2011) and subsequently as an INSA Senior Scientist. The latter position he held until his dying day. Best known as a phenomenologist, D.P. carried out research over a wide range of topics in particle physics and astroparticle physics for more than four decades, publishing around 200 papers, including some very comprehensive review articles. In the early years of his research career, he worked principally in strong interaction phenomenology, utilising Pomeron-Regge theory to predict the existence of exotic meson (tetraquark) and baryon (pentaquark) resonances – predictions which were experimentally verified nearly 35 years later. With the advent of hadron collider-based high energy experiments at CERN (UA1, UA2) in the early 1980's and later at Fermilab (Tevatron), D.P. changed his focus to collider physics. He contributed significantly to top quark physics, pioneering the effective use of lepton isolation criteria, now widely used in hadron collider experiments to eliminate backgrounds. Around the same time, D.P. spent a year on sabbatical leave at Dortmund, Germany, and there he started working on supersymmetry (SUSY) phenomenology, then in its infancy. One of the first to foresee the future role of SUSY as the 'standard model' for physics beyond the Standard Model (BSM), D.P. made many important contributions to the formulation of its phenomenology, including pioneering studies of missing energy signals, same-sign dileptons and other powerful measures which are routinely used today in SUSY searches by theorists and experimentalists alike. Charged Higgs bosons were almost an obsession with D.P., who firmly believed that the discovery of such an elementary scalar would be an unambiguous signal of BSM physics. Working with a wide range of collaborators, he laid out detailed strategies to look for the charged Higgs signal at hadron colliders, of which the most important was the use of the polarization state of tau leptons arising from charged Higgs decays. This technique is being currently used in the ongoing charged Higgs searches at the LHC. But D.P. went further and showed that the same tau polarization technique is also very effective in searches for SUSY particles. The fact that SUSY models provide a viable candidate for the dark matter relic density inspired in D.P. a lasting interest in astroparticle physics. For nearly two decades he worked on SUSY-based dark matter scenarios, including those with higgsino-, wino- or bino-dominated, or well-tempered/mixed neutralino relics. His forte was the combination of the explored neutralino relic density along with direct and indirect terrestrial probes of dark matter for various SUSY models and mass spectra. This fitted in well with his long-term interest in analysing collider signatures of the lightest neutralino. In the twilight of his long career, D.P. became interested in neutrino physics, and during the so-called golden years of solar neutrino physics (2000-05) he led a group of younger collaborators in a series of globally-acclaimed papers to analyse the experimental data in terms of neutrino oscillations with precise determination of neutrino masses and mixing angles. The quality and substance of D.P.'s body of work reflects his wide knowledge and deep intuition in the field of high energy physics phenomenology. His research bent was characterised by an uncanny knack for interpreting experimental data and a clear discrimination of the critical theoretical issues from the relatively unimportant ones. These qualities led to his wide recognition as one of the finest collider physicists in the world. D.P. was a warm-hearted, helpful and easily approachable person. He was very affectionate with younger people, a quality which helped many graduate students and postdocs to collaborate with him on easy terms. Starting from the late 1980's, he took great pains to teach collider physics to beginners, many of whom (including this author) later became his collaborators on some of his pet projects. He was also instrumental in starting an international Workshop on High Energy Physics Phenomenology (WHEPP) – a series which continues till the present day. This workshop acts as a nation-wide platform for vigorous discussion among Indian and international experts, and have provided a whole generation of young researchers around the country with their launching pad for mainstream research. D.P. was equally passionate about undergraduate teaching, involving himself in the National Initiative in Undergraduate Science (NIUS) programme of the TIFR-HBCSE as a mentor. He was a member of the advisory board of Prayas, the students' journal of physics published by the Indian Association of Physics Teachers (IAPT). He also used to teach regularly as a visiting faculty in the five-year integrated M.Sc. programme of the DAE-MU Centre of Excellence in Basic Science. D.P.'s scientific achievements were recognized in the form of the Meghnad Saha Award conferred by the University Grants Commission and the S.N. Bose Medal awarded by the Indian National Science Academy. He was a fellow of all the three Indian Academies of Science and a member of several important committees as well. In private life, apart from being a devoted family man, D.P. was a avid reader, with a deep interest in history. In the last years of his life, he developed a passion for the history of science, especially in ancient India, and went around the country lecturing on this topic in the hope that the next generation would learn from the mistakes of the past. A fitness freak, he was a body-builder in his young days, and enjoyed rude good health almost till the last day. Younger friends and collaborators would often find it hard to keep up with the septuagenarian D.P. in walking and swimming. He was a convivial and social person and easily made friends across decades of separation in age. However, a great tragedy in D.P.'s otherwise full life was the sudden demise of his elder daughter Kaberi, aged 29, in 2002, from complications following a burst appendix. Devastated by this loss, D.P. immediately filed a lawsuit against the hospital for criminal negligence, and by 2016, had won his case in the lower court. The matter is currently *sub judice* in a higher court, but the family is determined to see this through till their daughter gets justice. The sudden departure of D.P. has been a big blow to the high energy physics community, especially in India. Nevertheless, it may be hoped that he would be remembered as a role model for present and future generations of high energy physicists in our country.

The author is grateful to R.V. Gavai, U. Chattopadhayay, S. Goswami and, in particular, to Mrs. Monica Roy, for various inputs. Thanks are also due to S. Raychaudhuri for reading the first draft and suggesting some changes.

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TAA mourns the passing away of two of its notable alumni Dr. Yash Pal (1926-2017) and Prof. M. Multani (1937-2017)

Awards & Honours: January to June 2017

Prof. D. Narasimha –
Awarded Best Scientist" of the year 2017 by the South Indian ASDF Awards (SIAA) 2017 Committee

Prof. Pankaj Joshi
Awarded the first "Prof. A.R.Rao Research Award (2016)" by the Prof. A.R.Rao Foundation, Ahmedabad

Prof. Prahlad Harsha
Awarded the "Swarna Jayanti Fellowship", by the Department of Science & Technology (DST)

Prof. R.V.Hosur
Elected as the Fellow of the "International Society for Magnetic Resonance (ISMAR)"

Prof. Arnab Bhattacharya
Awarded the "Indira Gandhi Prize for Popularization of Science (2017)" by the "Indian National Science Academy"

TAA-National Science Day Public Lecture on **"The top scientific breakthrough of 2016: The detection of Gravitational waves by LIGO" by Professor Bala Iyer, ICTS-TIFR**

Professor Bala Iyer, ICTS-TIFR delivered the TAA National Science Day Public Lecture on February 28, 2017. The lecture was arranged in the Homi Bhabha Auditorium, Tata Institute of Fundamental Research, Mumbai 400005. He spoke on **"The top scientific breakthrough of 2016: The detection of Gravitational waves by LIGO"**

"Young students and post docs must regularly identify techniques and skills that would broadly empower them so that when the need arises, they have a broad armoury of tools to attack them with"

Predicted by Einstein a century ago, Gravitational Waves (GW) have eluded direct detection till recently. The first two detections of gravitational waves by Advanced LIGO in 2015 [1,2] and the remarkable success in reconstructing the black hole binary source are a sneak preview of what is possible in the coming decade as a new window to the universe opens and LIGO-India joins the global gravitational wave network. This new window to the universe has implications for astrophysics, cosmology and fundamental physics. No wonder then that this figured as the top scientific breakthrough of 2016.

Newtonian gravity was a remarkably successful theory for two hundred years describing motions of apples, tides, moon, planets and comets. Newton was aware that mass has two distinct roles: It is both a measure of inertia and a source of gravity. The universality of free fall in a uniform gravitational field thus implies the universality of the ratio of inertial mass and gravitational mass. Yet this remarkable coincidence has no fundamental role in Newtonian gravity. Newtonian gravity is also an instantaneous action at distance theory and thus gravitation propagates with infinite velocity.

Einstein discovered the Special Theory of Relativity (SR) in 1905. According to SR no interaction can propagate faster than the speed of light. In 1907 when Einstein was writing a review of SR he realized that Newtonian gravity was in conflict with SR. For the next eight years he worked towards resolving this conflict using as lodestone the Equivalence Principle that he described as the 'Happiest Thought in his Life'. It led him to General Relativity (GR), his relativistic gravity theory. GR is universally acknowledged as the epitome of mathematical elegance, conceptual depth and importantly observational success. In Einstein's view gravitation is synonymous with spacetime geometry and mathematically described by the curvature or distortion of spacetime. Physically, gravity manifests as a tidal effect, mathematically described by the geodesic deviation equation. 25 Nov 2015 was the centenary of this remarkable theory.

Any relativistic theory of Gravitation (like GR) must be consistent with Principle of SR. If the gravitational field of an object changes, the changes propagate thro' space and take a finite time to reach other objects. This leads to the possibility of GW from Einstein's equations like electromagnetic waves (EMW) from Maxwell's equations. GW are freely propagating oscillations of the gravitational field. They are oscillating tidal gravitational fields which propagate out from the source. For GW in GR, the tidal force field is oriented like a plus or a cross. If GW are incident normally on a ring of particles, it would be tidally stretched and squeezed in an oscillatory time dependent manner. Thus, to detect GW one must measure the amount of squeeze or equivalently the associated GW strain **h.** If two test particles are initially separated by distance L and if a GW signal passing through changes the separation by ΔL, the associated strain is defined by h = ΔL ⁄ L. GW were predicted by Einstein in 1916 as an important consequence of GR using Linearized gravity. He derived his famous quadrupole formula in 1918 which when applied to a massive dumbell consisting of two one ton masses separated by a couple of meters and rotating at a kiloHertz leads to a strain of 10^{-39}. Einstein observed "this must have a practically vanishing value in all conceivable situations". And like a "competent patent clerk" rightly assessed "Such ripples would be vanishingly small and nearly impossible to detect ..." In spite of the intervening century, we do not have a gravitational Hertz experiment. The reason is connected to two fundamental differences between EM and Gravitation: The weakness of the gravitational interaction relative to EM (10^{-39}) and the absence of dipole radiation in GR. This implies low efficiency for conversion of mechanical energy to gravitational radiation except in strong fields and at relativistic velocities. And feeble effects of GW on any potential detector we can build. Likely sources are signals produced by astrophysical systems where there can be potentially huge masses accelerating very strongly. In GR, as in EM, GW travel with speed of light, are transverse and have two states of polarization (+, x). GW carry away energy, angular momentum and linear momentum from the system. They are produced by accelerated motion of "masses". Unlike EMW, GW propagate essentially unperturbed through space as they interact weakly with matter. They are intrinsically non-linear since the wave energy density itself `gravitates'. The properties of the GW can be different in different theories of gravity providing the exciting possibility to test GR by GW observations.

During the first fifty years there was a Babel surrounding the understanding of GW. Finally, in the Chapel Hill conference of 1957, the physicality of GW was resolved and the quest for GW detection born. Felix Pirani pointed out that even if the generation of GW was a complicated problem, the tidal effect of GW was unambiguous and given by the geodesic deviation equation. This led to the famous sticky bead argument credited to Bondi and Feynman: If one had a rod on which snugly fit rings could move, the tidal force of GW would slide the rings up and down the rod and frictionally heat a mechanical system connected to it. Joe Weber and John Wheeler were at the meeting and in 1960 Weber proposed his bar detector to detect GW. In 1969 he made his claim of GW detection which unfortunately could not be confirmed by other researchers with more sensitive detectors. Joe was the tragic pioneer in the field of GW detection. On the theoretical front, in the 1960's, Chandrasekhar addressed the radiation reaction problem. How does emission of GW affect the emitting system when its self-gravitating? He showed, that energy and angular momentum (AM) radiated as GW was correctly balanced by the loss of mechanical energy and AM. This gave astrophysicists confidence that GR was physically reasonable and well behaved. Work by Bondi and collaborators also rigorously proved that mathematically GW were described by the News function. Though GR had earlier led to novel possibilities for end states of stellar evolution like neutron stars and black holes, the discovery of pulsars and quasars led to the birth of Relativistic Astrophysics in the 1970's. The linear stability of Schwarzschild black hole and the existence of quasi-normal modes of black holes were important results due to Vishveshwara in this period.

A watershed event in the GW story was the discovery in 1974 of the binary pulsar B1913+16 by Hulse and Taylor. If GR is correct, this system must emit GW and inspiral inwards. This was first observed by Weisberg and Taylor in 1982 and observations over the next thirty years confirm this prediction of Einstein's GR. Hulse and Taylor were awarded the Nobel Prize in 1993 for the "*discovery of new type of pulsar, a discovery that has opened up new possibilities for the study of gravitation.*" Since then many other binary pulsars have been discovered, all consistent with predictions of GR, the most spectacular being the double pulsar.

A straightforward application of the quadrupole formula to 1913+16 (double pulsar) proves that it will merge and coalesce in 300 (80) million years implying the existence of binary neutron stars emitting GW for *hundreds of million years* before coalescing spectacularly. The late Inspiral and merger epochs of compact binaries of neutron stars or black holes thus provide us possible strong sources of GW for detectors like LIGO and Virgo in their sensitive frequency range 10 Hz - 10 kHz. The waveform is a CHIRP, that is, a signal whose amplitude and frequency increase with time. Near merger, these systems are highly relativistic with $v/c \sim 0.4$. A binary neutron star system moving at velocities close to that of light in Virgo cluster produces a strain of $h \approx 10^{-21}$ leading in km scale Interferometers to a 10^{-18} m displacement. The miniscule strain and associated tiny displacement (1/1000th fm) must be measured to detect the GW. Bigger the device, bigger the displacement effect. To contrast: the classic Michelson Morley experiment of SR corresponds to a displacement measurement of 5×10^{-9}m, 10 orders of magnitude larger! The strain amplitude of GW is inversely proportional to distance (Luminosity). Thus a f*actor N increase in detector sensitivity, leads to factor N gain in distance reached and n^3 in Number of potential events.*

Advanced LIGO, was the discovery instrument. A LIGO consists of four km long interferometers at the two observatories at Hanford and Livingston. It was the Mark II phase of the two step strategy. It began with Initial LIGO (1994 -2010) to demonstrate the technology involved. It then moved on to A LIGO in 2008, envisaged to be 10 times more sensitive at design sensitivity. Interferometer mirrors act as test masses and the passage of GW induces differential arm length change proportional to GW strain amplitude. This generates power fluctuations in GW readout port measured by photodiodes. A simple 4 km Michelson is not sensitive enough. Fabry Perot cavities allow light to bounce back and forth along arms about ~100 times increasing the sensitivity 100 fold. Further, by power recycling, i.e if light is "recycled" about ~50 times, fringe sensing is improved. By signal recycling, i.e. reflecting the signal back into interferometer, one can tailor the frequency response. By use of photo-detectors one can finally sense 10^{-11} of a fringe. The interferometer acts as a *transducer* converting GW to photocurrent proportional to the strain amplitude. One needs to beat a number of fundamental and technical noise sources that affect measurement at sub-nuclear length scales. This requires instrument science at the frontiers of physics fundamental limits. The keys to higher sensitivity in Advanced LIGO are higher power laser, lower thermal noise mirrors and finally better vibration isolation to deal with dominant noises at high, mid and low frequencies respectively. The other km scale facility is Virgo, a 3 km interferometer at Cascina near Pisa.

The remarkable and sensitive instrument needs to be complemented by an exquisite theory and efficient data analyses infrastructure since GW are WEAK SIGNALS buried in LARGE NOISE of detector. They require Matched Filtering (MF) both for their Detection or Extraction and Parameter Estimation or Characterization. Matched Filtering involves Correlating a KNOWN SIGNAL with the NOISY DATA and the success of MF requires an accurate model of the signal using GR. The challenge is immense since unlike the solar system where $v/c \sim 10^{-5} - 10^{-4}$ or binary pulsars where $v/c \sim 10^{-3}$, for LIGO sources like CCB, $v/c \sim 0.4$. The paper entitled "Last Three Minutes: Issues in Gravitational wave measurements of Coalescing Compact Binaries; Cutler et al Phys. Rev. Lett 70 2984, (1993)" highlighted the challenge in describing the Inspiral, Merger and Ringdown phases of the CCB. Its progress over the next two decades included foundational contributions to source modelling at RRI in a group around me and on GW DA at IUCAA around Sanjeev Dhurandhar. This constitutes the GW legacy in India starting 1990. Students and post-docs from these groups after post-doc stints in GW groups abroad are back in faculty positions in India and the current generation leaders of GW research in India. Many of these groups contributed to the analysis of the Discovery paper; there are 37 authors on Discovery paper from India.

The First Direct Detection of Gravitational Waves was made by LIGO Scientific and Virgo Collaborations [1]. On Sept 14 2015, just four days before O1, the First Science run of a LIGO, was about to begin, the two LIGO observatories in Hanford and Livingston (USA) detected a coincident gravitational-wave signal. The signals arrived in the two detectors within ~7 milliseconds and had a combined signal-to-noise ratio of 24. Source information is uniquely encoded in phase/amplitude evolution of GW and hence using the data analyses infrastructure developed, one can check the signal was consistent with a signal expected from the coalescence of two black holes. The residuals obtained by the difference of observed data and expected signals is consistent with noise. GW150914 with SNR=24 was a very loud event. The matched filter search involves a cross-correlation of L1, H1 data streams using 250,000 BH waveform templates covering 1-- 99 M_{sun}. It had 10 GW cycles over 0.2 sec and verified to be a "5 sigma" detection as follows. The background is computed by time-shifting coincident data in 100 ms steps to produce 5×10^6 years synthetic data. One can analyse this to show the false alarm probability $< 2 \times 10^{-7}$, corresponding to a false alarm rate < 1/203,000 years and hence a significance $> 5.1\sigma$.

One can estimate parameters of the two initial black holes and the final remnant and conclude that it involved a binary consisting of 36 M_{sun} BH and 29 M_{sun} BH merging into a 62 M_{sun} BH 1.3 billion light years away. One can see that this was the most powerful astronomical source since in this case, energy corresponding to 3 $M_o c^2$ is radiated as gravitational waves in ~0.1 seconds corresponding to peak power emission of 10^{49} W! (which is more than the luminosity of all the stars in the universe).

In O1 there were two other interesting events as well. A candidate LVT151012 involving BH of masses 23M^{sun} and 13 M^{sun} merging into a 35 M^{sun} BH 3 billion light years away. Detailed analysis showed that this could not be confirmed at 5 sigma level. The second definite detection GW151226 [2] corresponded to a binary involving 14Msun BH and 8 Msun BH coalescing to a 21 M^{sun} BH 1.4 billion light years away. The events were of different kinds. *GW150914 was a high SNR event, clearly visible in the frequency-time plot involving the merger in detector's band of a massive binary.* GW151226 on the other hand was not so visible. It needed match filtering and corresponded to inspiral-plunge in detector's band of a relatively lower mass binary.

Given current tight constraints on GR (from e.g., solar system, binary pulsars), can any GR deviation be observed with these LIGO sources? Firstly, the residual of the data after subtracting the best-fit GR template is consistent with noise. Secondly, final mass/spin estimated from the inspiral and post-inspiral parts of the signal are in agreement. Thirdly, post-Newtonian coefficients estimated from the data are consistent with the GR prediction and lastly the final part of the signal is consistent with quasi-normal-mode ringing predicted by C.V. Vishveshwara (1970). One can also show that the propagation effects are consistent with a massless graviton. Albert Einstein is right again.

GW150914 merits many gold medals. It was the first direct detection of GW. The first detection of a binary black hole that merges within the age of the universe and finally the first observation of stellar-mass black holes with mass $\gtrsim 25\, M_{\odot}$. The last points to an environment of weak massive-star winds and hence of low metallicity. Based on the two definite events and one likely candidate from O1, the estimate of BBH sources is 9 – 240 binary merger events every year in every Gpc^3 of the local Universe. This new population of GW sources can produce a detectable "stochastic background of gravitational waves" $1.2^{+1.9}_{-0.9} \times 10^{-9}$ (25 Hz). It is amazing that we can reconstruct that the GW came from a BBH system at cosmological distance and was emitted 1.3 billion years ago when on earth transition was happening from single cell to multicellular forms of life!! **LIGO** is an acronym for Laser Interferometer Gravitational-wave Observatory and with the first detection already the **O** in LIGO is well justified.

How well is the localisation of these sources on the sky and how well was the associated EM Follow up? GW150914 hit the Louisiana detector first and 7 milliseconds later the Washington detector, showing that the signal came from somewhere in the southern hemisphere. The source localisation of GW150914 was ~ 590 sq. deg and the alert sent to MoU partners resulted in follow up in various EM bands. No EM counterpart was found as generally expected from BBH mergers. The above current sky localization based on the two LIGO detectors is rather poor. Even if Virgo joins the network the localization is poor for sources in and close to the plane of the LIGO-Virgo network. The possibility of improved sky localization over most of the sky is the prime motivation of LIGO-India.

With Advanced LIGO, we have achieved the technology to make a direct detection of gravitational waves 100 years after Einstein predicted them. We also have corresponding progress in the two body problem in general relativity and related data analyses to detect GW, characterize them and begin to test general relativity. The first detection involved BH binaries (known-unknowns), Observing run O2 started on November 30th, 2016 as planned and discovered on Jan 4 2017 the third BH binary [3]. Virgo will join in before the close of O2 by the end of August 2017. Currently we expect to see 1 BBH per month. This could scale to 1BBH per day as LIGO sensitivity increases by a factor of 3 in the final upgrade. Shall we see neutron star binaries (known-knowns) or neutron star black hole binaries (known-unknowns)? Or will GW astronomy reveal something entirely unspeculated (unknown unknowns)? A MAJOR revolution in astronomy is round the corner with a facility in India having the opportunity to play a key role. LIGO-India will be a critical element of the Global GW Detector network for GW Astronomy. Feb 11 2016 was the Nov 7 1919 of our generation. What more would Einstein want at the centenary of GR and GW when the universe has released the new GW symphony for the maestro?

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An interview with Prof. Bala Iyer [*"Young students and post-docs must regularly identify techniques and skills that would broadly empower them so that when the need arises, they have a broad armory of tools to attack them with." in the beginning of the interview*"]

Prof. Bala Iyer delivered the TAA-National Science Day Lecture on 28th February 2017 at TIFR. Here is an interview with the speaker.

TAA: Thank you for giving us an opportunity to talk to you for the TAA newsletter. To start with, it would be nice if you could tell us how you got interested in physics and in particular gravitational waves.

SPEAKER: After school, I joined Ramnarain Ruia College where I was exposed to Professors Gupte and Godbole whose physics textbook was inspired by authors like Sommerfeld. They encouraged us to appreciate physics from classics like Halliday and Resnick and examined us in the first term by a non-standard physics test requiring one to think rather than remember. This got me more inclined to physics. I also vividly recall a popular article by Jayant Narlikar entitled 'The Arrow of Time' in Science Today that mystified and fascinated me. It created a vague desire and urge to think about such basic problems and hopefully later contribute to their resolution. It was these subconscious fantasies that reinforced interest in physics and eventually general relativity. Courses by Arvind Kumar and Abbas Rangwala during Masters at University Department of Physics (UDP), Kalina empowered me and interactions with them exposed me to the modern landscape of physics research. I worked with Arvind Kumar for my PhD on issues of Dirac field theory in Kerr and Rindler spacetimes. Familiarity with Chandrasekhar's work on black hole perturbations during this period helped me in my collaboration with Vishveshwara at Raman Research Institute for over a decade during which we worked on implications of general relativity for some astrophysical problems. My interest in gravitational waves started seriously during a sabbatical with Thibault Damour at DARC, Meudon and IHES, Bures-sur-Yvette in 1989-90. The time was just right. The Nobel for the discovery of the Hulse Taylor Binary Pulsar, the proposals to build LIGO and Virgo and the need to model inspiralling compact binaries of neutron stars and black holes were just around the corner. After that, it was gravitational waves for breakfast, lunch, dinner and dreams.

TAA: Can you tell us about your childhood and early education.

SPEAKER:. I grew up in Kalyan in the suburbs of Bombay and studied in a convent school. Teaching of maths and science then was not particularly inspiring and the students by and large had to fend for themselves. Unfortunately, in a majority of schools even today, the situation is no better. I was fortunate that in spite of a strain on their resources my parents arranged for tutoring at home in subjects I was weak in and by teachers who were committed and passionate about their calling. By the time I was in high school, I was able to study on my own and overcome the handicap of limited mentoring in the school in these subjects. The influence a good teacher can have is not diminished even today and their scarcity is a significant contributor to the creation of unemployable students.

TAA: What challenges did you face and how did you overcome those challenges during your journey so far?

SPEAKER: The challenges were what a student of physics faces in most colleges even today. After Inter Science in my time or Standard 12 these days those who remain to do a degree in Basic science out of genuine interest find themselves in a minority and socially perceived as also-rans relative to those who go into professional courses. The courses and teachers at this level are mostly uninspiring and a peer group motivated to excel generally absent. In colleges where there was a group of aspirational students, initiatives by the students to form discussion groups reading Feynman Lectures or Berkely Lectures or special topics like relativity or mathematical methods helped overcome the handicaps. This lack of rigorous preparation in core physics and maths topics impacted the ease with which novel problems could be tackled efficiently. Precious time was lost in mastering techniques at the start to acquire familiarity with the tools a well-trained researcher should have had. Investing quality time at the start of a new project to identify and master more broadly the underlying techniques was one of the ways I overcame those challenges. Young students and post-docs must regularly identify techniques and skills that would broadly empower them so that when the need arises, they have a broad armory of tools to attack them with. Fortunately during our M.Sc at UDP, Kalina, lectures by Arvind Kumar and Abbas Rangwala and experiments in MC Joshi's Lab provided the supplements for our academic under-nourishment in BSc years.

TAA: Any memorable incident/anecdote?

SPEAKER: A couple of incidents.. 1) Chandra's book on Mathematical Theory of Black Holes came out during my PhD and it was memorable to find a small reference to a paper by me and Arvind in that masterpiece. 2) I still recall the pleasure and enlightment I experienced by the insight emerging from a lecture of Arvind Kumar on the experiment by Wu to look for parity violation in beta-decay.

TAA: Could you comment on India's role in one of the biggest discovery of this decade: discovery of the gravitational waves.

SPEAKER:
India's role in the discovery of gravitational waves are of different categories.. Let me elaborate.. Firstly, the discovery was the joint work of two large international collaborations – the LIGO Scientific Collaboration (or LSC) and the Virgo collaboration. India was represented in the LSC by the IndIGO-LSC which had thirty-seven members from nine Indian institutions. Between them the members either worked on different aspects of data analyses of GW from current LIGO observations or towards realizing the future LIGO-India. In particular, the group at ICTS-TIFR proposed and implemented a test of Einstein's theory of general relativity in the dynamic strong field regime by measuring the mass and spin of the final black hole from the "inspiral" part of the signal and checking their consistency with the same parameters measured from the "post-merger" signal. They also contributed to the analysis to infer the properties of the remnant black hole. Groups at the Chennai Mathematical Institute, the Indian Institute at Thiruvananthapuram and Kolkata contributed to another test by measuring the coefficients of the post-Newtonian expansion from the observed signal. The TIFR group worked on bounding the orbital eccentricity. The group at IUCAA and other Indian groups contributed to the understanding of the response of the detector to the signals and terrestrial influences, to the method used to detect the signal, and to the search for a possible electromagnetic counterpart using optical telescopes. The second category of contribution relates to the significant Indian contribution to GW research over the last twenty five years as reflected by the references cited in the discovery paper. This comprises the Indian legacy on Gravitational wave research in the areas of source modelling of inspiralling compact binaries at RRI - in a group around me working in close collaboration with the group around Blanchet and Damour in France – and a group around Sanjeev Dhurandhar at IUCAA working on GW data analyses aspects.

Thirdly, the seminal work of C.V. Vishveshwara from the 1970s on the characteristic oscillation modes of black holes, called "quasi-normal modes" in the ringdown of the black hole.

TAA: Being one of the lead investigator, could you tell us something about the upcoming LIGO-INDIA project?

SPEAKER:

The LIGO-India project is for the construction and operation of an Advanced LIGO Detector in collaboration with LIGO Laboratories, USA and its international partners Australia, Germany and UK. The objective is to set up the Indian node of the three-node global Advanced LIGO detector network by 2024 and operate them in coincidence for a few years. The entire hardware component of the advanced LIGO detector, along with design and software, is to be provided by LIGO-U.S. and its international partners. The entire infrastructure, including the two four-kilometre ultra-high vacuum (UHV) beam tubes, with associated chambers, corner and end stations, related labs and clean rooms, as well as the team to build and operate the observatory will be the Indian responsibility. LIGO Laboratories will 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 of LIGO-India. The inclusion of LIGO-India greatly improves the angular resolution in the location of the GW source by the LIGO global network. For the discovery event if LIGO-India was in operation, there would have been a 100-fold improvement in the angular resolution making electromagnetic follow up more feasible. Beyond the momentous discovery itself, the excitement following the first detection relates to the opening up of a new observational window into the dark universe and its potential to impact our understanding of astrophysics, cosmology and even the fundamental nature of gravitation itself. LIGO-India groups at RRCAT, IPR and IUCAA have complementary responsibilities and have been steadily working even in the pre-approval period. The site selection committee at IUCAA has looked at over 22 sites and shortlisted three 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. The team at the IPR has prepared system requirement documents, conceptual drawings and engineering drawings for the sophisticated civil infrastructure and UHV systems in consultation with LIGO Laboratories. The team at the RRCAThas been finalising plans for setting up an off-site laboratory to receive the laser systems for LIGO-India. Its members are working on the pre-stabilised laser in collaboration with colleagues in Germany and are also experimenting with the production of fused silica suspensions for the optics used in Advanced LIGO. IUCAA has built up a state-of-the-art Tier 2 LIGO data centre and also initiated the expansion of the experimental team beyond IPR and RRCAT by a series of meetings involving experimenters from IITs, IISERs and other DAE institutes. ICTS-TIFR has set up a Tier-3 LIGO data centre.

TAA: What do you think about a career and future opportunities available in gravitational waves for today's students?

SPEAKER:

Over the last decade, the Indian GW community has spread to a number of educational and research institutions in India. As members of the LIGO Science Collaboration, they have made major contributions to the development of novel techniques both to identify the weak GW signals and exploring GW astrophysics. GW researchers in LIGO-India have expertise in precision metrology, laser and optics development, ultra-high vacuum techniques and control systems. A prototype detector is being built for training and research at TIFR, Mumbai by Unnikrishnan. Computing facilities dedicated to GW science have come up in IUCAA, Pune, and at ICTS-TIFR, Bengaluru. There is increasing participation from the Indian astronomy community in anticipation of this new emerging frontier of "Electromagnetic follow up" of GW events. As the Global GW Network expands to include LIGO-India, successful operation of advanced detectors will transform the field from GW detection to GW astronomy. GWs provide complementary information to electromagnetic and neutrino observations. By combining observations of a single event using these multi-messengers, it is possible to gain a more complete understanding of the source's properties in the coming decades. Even more, LIGO-India has the potential to impact precision experiments and cutting-edge technology in the country. The endeavour has interfaces with quantum metrology, laser physics and technology, vacuum technologies, optical engineering, sensor technologies, control systems, grid and cloud computing. As emphasized by Beverly Berger of the NSF, USA: "*Every single technology they are touching they are pushing and there is a lot of technologies they are touching.*"

TAA: Learning's and insights from your overall experience that will be useful to TIFR community and particularly to the youngsters.

SPEAKER:

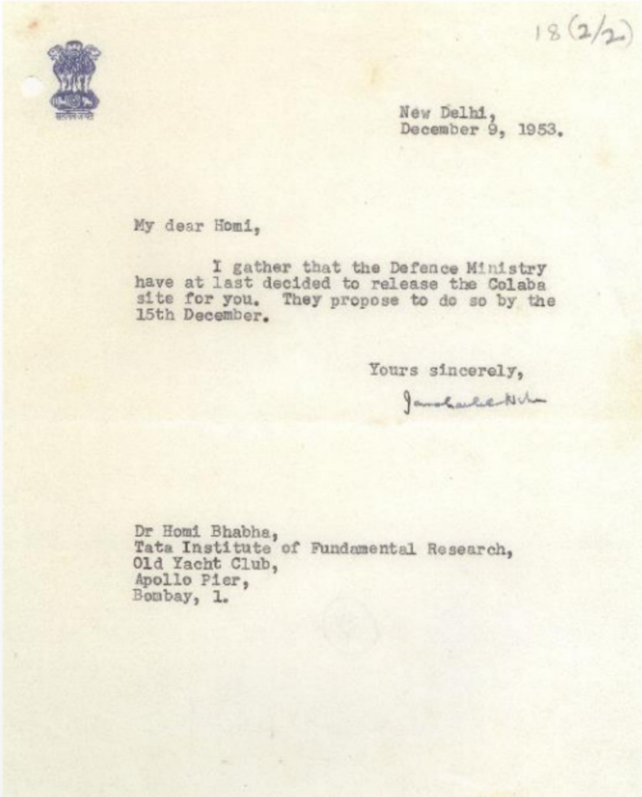
As the Chair of the IndIGO Consortium from its inception in 2009, it has been a very different learning experience for one with my background. In an article that Tarun Souradeep and I wrote for Frontline after the discovery, we tried to introspect and delineate on what IndIGO did right. First: it projected well into the future looking for an emerging opportunity and served as a channel to induce and assist Indian researchers abroad to explore possibilities of returning and contributing to the national effort. It also consolidated sub-system expertise scattered across different laboratories in India under a common umbrella taking critical inputs from the GW International community. Second: As an informal collection of researchers devoid of any institutional affiliation, bold uninhibited steps driven solely by scientific and technological considerations could be taken. Lastly, the open and non-institutional nature of the consortium made possible an influx of experts from different institutions and from other related fields of experimentation and theory. The globally cooperative and collaborative nature of GW science served to inculcate the spirit of working effectively in a large scientific collaboration. However, all this is just the setting up the base camp to scale the Everest of building LIGO-India. Far tougher challenges lie ahead for this "social experiment" of multi-institutional scientific collaboration in India as it transforms from an informal consortium to a formal project structured by the funding agencies. Post detection, the global community is also undergoing significant organizational changes to deal with the imminent Observational-Era challenges in the coming decade; LIGO-India and IndIGO will need to take into account these evolving paradigms to deliver and make a strong impact as one transits to a more exciting but also more complex epoch in GW science.

TAA: Professor Iyer, it was a pleasure to be in conversation with you. Thank you very much.

TIFR Archives

The TIFR Archives is a repository of institutional records and a storehouse of resources for reconstructing the historical setting within which one of India's premier science institution was founded. Here are a few images from the repository. Their website http://www.tifr.res.in/~archives/ has a lot more for you to browse.

Work was carried out in these hutments before the TIFR buildings came into existence



18 (2/2)

New Delhi,
December 9, 1953.

My dear Homi,

I gather that the Defence Ministry have at last decided to release the Colaba site for you. They propose to do so by the 15th December.

Yours sincerely,
Jawaharlal Nehru

Dr Homi Bhabha,
Tata Institute of Fundamental Research,
Old Yacht Club,
Apollo Pier,
Bombay, 1.

The proposed construction site of TIFR Building

Construction of Homi Bhabha Auditorium