ideas, the problem of defect integrable models was solved by Kundu and his colleagues, including defect nonlinear Schrödinger and Toda chain equations. It is in the fitness of things that his last work, accepted for publication on 3 January 2017, documents Kundu's commitment to direct efforts in controlling the hazardous near-shore oceanic waves by implementing his theoretical ideas on leakage-based methods. This is a sequel to his concern to control the devastating consequences of extreme events like the December 2004 Indian Ocean tsunami.

Kundu was recipient of many honours. Apart from the ones mentioned above, he was elected to the Fellowship of the Indian National Science Academy, New Delhi (2014) and Indian Academy of Sciences, Bengaluru (2015). He was a member of the Editorial Board of the *Proceedings of the Royal Society of London, Series A* since 2012. He has trained several outstanding students at SINP and published over 100 papers besides several articles to Proceedings and editing important books. It is remarkable that Kundu could achieve all these despite his life-long affliction with acute myopia and later heroically fighting leukaemia during the final four years of his life.

Kundu was always brimming with novel ideas to expand the horizon of integrable nonlinear systems in multipronged ways. Even under severe physical strain later in his life, he could overcome it by concentrating on his desire to invent new integrable systems, understanding their mathematical structures and applying the results to new physical contexts. These traits have enabled him to develop deep friendship with like-minded scientists both in India and abroad, who all deeply mourn his demise at the pinnacle of his career. Kundu retained his passion for travel to newer places and tasting exotic food, as well as writing science fiction stories and poetry, especially in his mother tongue, Bengali. He remained cheerful all through his life and was endeared by everyone. He is survived by his wife, daughter, and a grandchild.

M. LAKSHMANAN[1,*]
BIKAS K. CHAKRABARTI[2]

[1]*Centre for Nonlinear Dynamics, Bharathidasan University, Tiruchirappalli 620 024, India*
[2]*Saha Institute of Nuclear Physics, Kolkata 700 064, India*
**e-mail: lakshman@cnld.bdu.ac.in*

# C. V. Vishveshwara (1938–2017)

C. V. Vishveshwara (Vishu) is associated to most of us with quasi-normal modes or the ringdown of a black hole. The prediction that his simple calculations made was dramatically verified after 46 years with the discovery of gravitational waves by LIGO, which was almost a year before he breathed his last on 16 January 2017 in Bengaluru. It was, therefore, most fortuitous that he could experience the exhilaration and satisfaction of his contribution when the whole world was cheering and applauding. Vishu will be remembered for a long time not only for his seminal contributions to understanding black holes, but also fondly for the word pictures and the Sydney Harris-like cartoons he created to share with his professional colleagues and the lay public the esoteric consequences of Einstein's general theory of relativity. His talks inspired generations of students to a career in science, and through the activities at the Jawaharlal Nehru Planetarium, Bengaluru and the Bangalore Association for Science Education (BASE) the inspiration lives on.

Vishveshwara was born on 6 March 1938 in Bengaluru. He had his schooling there and then went to Mysore University for further studies. He obtained the B Sc (Hons) degree in 1958 and M Sc degree in 1959 from Central College of the then Mysore University. He then went to USA for higher studies. After getting his A.M. from Columbia University, New York, in 1964 Vishu moved to the University of Maryland from where he got his Ph D in 1968. His thesis advisor was C. W. Misner, the 'M' of the directory of the universe, MTW. His thesis subject was 'Stability of Schwarzschild metric'. After stints as a postdoctoral fellow and a visiting faculty member at the Institute of Space Studies (1968–69), Boston University (1969–72), New York University (1972–74), and University of Pittsburgh (1974–76), Vishu returned to Bengaluru in 1976 and joined the Raman Research Institute (RRI). In December 1992, he moved from RRI to the Indian Institute of Astrophysics (IIA), Bengaluru as a senior professor, from where he retired in 2005.

One of the most important and bizarre predictions of general relativity is the existence of black holes – objects from which nothing can come out, including light. It marks a one-way surface which can only be crossed one way but not the other – things can fall in but nothing can come out. A brief historical aside is not out of place to give a flavour of the times when Vishu's important papers were written.

Relativity revolutionized our understanding of space and time by first uniting them into a flat four-dimensional space–time in special relativity, and subsequently for describing gravity making it curved and dynamic in general relativity. Gravity is no longer an external force but synonymous with the geometry of space–time. In 1915, Einstein finally arrived at the correct field equations completing the quest he began in 1907 to obtain general relativity, his relativistic theory of gravitation. Mathematically, the equations were complicated and so he was surprised that within a year Karl Schwarzschild discovered an exact solution of these equations representing a spherically symmetric, asymptotically flat vacuum solution, whose outer region is strictly static. The solution had an unusual feature that a certain component of the metric vanished while another diverged at what was referred to as the Schwarzschild singularity, or better the Schwarzschild surface. Though, in 1939, Oppenheimer and Snyder showed that a person who rides through this surface on an imploding star will feel no infinite gravity or see no breakdown of physics there, these results were not taken seriously due to the mental connotation associated with the word 'singularity' and due to the simple dust model used in the treatment. These objects were referred to as frozen star in the Soviet Union and collapsed star in the West. The realization that this was due to a choice of coordinates or a coordinate singularity was long time coming and conclusively settled in 1958 by Finkelstein (and later in

1960 by Kruskal), who discovered a new reference frame for the Schwarzschild geometry. In December 1967, in his lecture on 'Our universe, the known and unknown', John Wheeler christened these objects as black holes, an idea that intrigues and fascinates the scientists and the lay public even to this day.

General relativity is a complex mathematical theory and often involves subtleties in its physical interpretation related to the choice of coordinates used in its formulation. Can one use a description with more well-behaved coordinates? Even if mathematically a black hole solution exists, the possibility of it being a physical object in nature depends on whether it is stable. If the black hole is an object from which no information can escape, how can one look for it? Can one provide a mathematically elegant description of the physical effects of a rotating black hole like gyroscopic precession? Vishu's seminal research centred on these topics and earned him the fond title of 'black hole man of India'.

Among Vishu's classics on this topic is a brief elegant paper using Killing vectors to provide a coordinate invariant distinction between the stationary Kerr and static Schwarzschild black hole cases and the consequent existence of the ergosphere[1]. Regarding this work Jacob Bekenstein commented[2]: 'I was familiar with the Vishu theorem that the infinite redshift surface of a static black is always the horizon. At that time black hole physics was just getting started and such neat relations between black hole features were rare. Vishu's theorem was a welcome hard fact in the middle of such folklore and helped clarify in mind what black holes were about. At the conference (GR6) I had a long talk with him and I vividly remember being impressed by the range of research problems he had going simultaneously.'

Vishu was the first to prove the stability of non-rotating black holes under linear perturbations[3]. Regarding this Brandon Carter remarked[2]: 'Vishu was one of the first to appreciate the importance of this problem and who played an important role in persuading others to take the problem seriously as something of potential astrophysical relevance by providing the first convincing proof that at least in one case namely the Schwarzschild solution, such an equilibrium state can be stable.' Elaborating further, Bernard Whiting wrote[2]: 'Vishveshwara's original discussion of stability showed that there was no superficial case establishing the instability basically by dealing with single modes and by demonstrating the positivity of effective potentials. Establishing point-wise boundedness requires use of more refined tools leading to a method that differs markedly in substance but not at all in essence from the relatively simple positive potential approach. Vishu made a number of significant breakthroughs....'

Vishu was the pioneer who explored how black holes respond when externally perturbed[4] and proved that regardless of the perturbation, Schwarzschild black holes get rid of any deformation imparted to them by radiating gravitational waves with a frequency and decay time that depended only on their mass. These characteristic waves are technically termed quasi-normal modes, which is why after the announcement of the gravitational wave detection by LIGO, Vishu laid claim to the nom de plume 'quasimodo of black holes'. Quasi-normal modes are like the dying tones of a bell struck with a hammer and are referred to as the ringdown radiation. Vishu's work is fundamental to our understanding of black holes and began a new chapter in how to study them.

Many of us met Vishu during the Einstein centenary symposium at Physical Research Laboratory, Ahmedabad in 1979. Though we have other wonderful memories of the symposium, the most memorable one was Vishu's lecture entitled 'Black holes for bedtime'. It was a magical experience; an exotic cocktail of science, art, humour and caricature. Equations were not necessarily abstract and unspeakable, and could well be translated in the best literary tradition if you were Vishu.

At RRI and later at IIA, Vishu explored problems in classical general relativity with possible astrophysical implications. Perturbations of black holes in general relativity carry signatures of the effective potential around them and one could look for them by examining neutrinos in gravitational collapse or ultra-compact objects. Could one discern possible differences between black hole solutions in general relativity and other theories of gravity by looking at their quasi-normal modes and the properties of their horizons? How different are black hole solutions in cosmological backgrounds from those in the usual asymptotically flat ones? How does one use the Frenet–Serret formalism to study gyroscopic precession, general relativity analogs of inertial forces and characterize black holes in higher dimensions in a covariant and geometric manner? Other mathematical issues studied related to separability of different spin perturbations in general relativity, the role of the Killing tensor in separability of wave equations among others. It was always a pleasure working with Vishu. There was no pressure, no generation gap, a natural possibility to grow and contribute your best, an easy personal rapport, a refreshing sense of humour, an unassuming erudition and most importantly, a warm and wonderful human being.

Together with J. V. Narlikar, Vishu played a key role in bringing long due recognition to the doyens of general relativity P. C. Vaidya and A. K. Raychauduri. A volume entitled *Random Walk in Relativity and Cosmology* co-edited by them was released in 1986 at RRI and the royalties from its royalties supplemented by royalties of the International Conference on Gravitation and Cosmology (ICGC) proceedings used to setup the Vaidya–Raychaudhuri Endowment Lecture of the Indian Association for General Relativity and Gravitation (IAGRG). Vishu was closely involved in the group that initiated, planned and organized UGC Schools on general relativity and cosmology in the 1980s. The motivation was to extend Indian research in exact solutions in general relativity to modern research frontiers in cosmology, early universe and relativistic astrophysics. This led to the ICGC meetings organized every four years because it was recognized that due to limited resources, participation of Indian researchers in the International Society of General Relativity and Gravitation (ISGRG) meetings was limited. Creating an opportunity for the IAGRG community to interact with international experts on frontline research areas in relativity and cosmology in India was necessary to assist in improving the quality and relevance of general relativity research in India. These meetings also brought out the cartoonist in Vishu during the first ICGC in Goa. Between sessions cartoons would appear on the screen anonymously and by the end of the meeting multiple reprint requests for them. The staid Cambridge University Press was happy to include them in the proceedings and

Vishu's cartoons in the ICGC proceedings were a treat to look forward to. The series of cartoons on gravitational waves in those proceedings deserve special mention. Alas, they are incomplete since he could not make one after the discovery. Just on the day he passed away, Nils Andersson wrote Vishu an email: 'I have recently done something that I think might amuse you. I have written a little book involving Einstein, relativity and a fair bit of fictional freedom. Now, I think it is fair to say that my attitude to this project has been heavily inspired by your story-telling, your drawings and the bathtub book' (see ref. 5 regarding the book).

Vishu's public lectures inspired a number of students all over the country. His lectures at the Bangalore Science Forum, started by his guru H. Narasimhaiah, always drew huge numbers. Vishu was a best-seller. And, he never disappointed the audience. Without diluting the profound ideas that he would discuss, Vishu would lace the talks with subtle humour that came seamlessly. At Vishu's passing, countless echoed Sathyaprakash who exclaimed 'This is devastating. I have lost a teacher, a mentor and a friend. More than anything else we are going to miss his "serious" sense of humour in all walks of life, especially science'.

Together with a committed group that included Sanjay Biswas, Vishu was involved in bringing out *Bulletin of Sciences* from 1983 to 1993 to setup a forum to seriously address the social impact of science and technology. To find means of sustaining it financially, he co-edited with Sanjay Biswas and D. C. V. Mallik an interesting volume called *Cosmic Perspectives* that was dedicated to the memory of M. Vainu Bappu. Together with A. Ratnakar, Vishu was instrumental in setting up the RRI Film Club in the 1980s to get access to movie classics from National Film Archives in Pune and from the consulates like the German and French ones.

The Jawaharlal Nehru Planetarium (JNP), Bengaluru is a testament to Vishu's vision which showcases his multi-faceted personality in science communication and education. Starting as its founder Director in 1988, Vishu brought together a dedicated and talented team and inspired them to build a world class planetarium scripting unique shows integrating the best in science and astronomy with the best in world and Indian history, art, literature and music. By example, he set up high standards for all the JNP personnel and mentored them till the very end. But JNP was not to be just a theatre. It had to play a role in science education in the city. Thus, in 1992 the BASE was set up by Vishu to systematically expose, attract and mentor students from schools and colleges for a career in science. It may surprise many that in spite of being a pure theorist, Vishu firmly believed in doing science experiments. Through activities like 'science in action', he emphasized the importance of bringing out in young students the joy of seeing scientific phenomena. That was a way to attract them to science. In fact, this philosophy of 'doing' science underlined every activity that was visualized at JNP in the coming years: SEED (Science Education in Early Development) for middle-school children, SOW (Science Over the Weekends) for high-school children and at the pinnacle of the educational programmes, REAP (Research Education Advancement Programme) for undergraduate students. SEED, SOW and REAP, all have a strong presence of experiments that make the programmes dynamic and vibrant and endearing to students. During the last 20 years, all these programmes have seen a steady growth in the number of students attending them and also in attracting quality students with a potential to excel in a career in science. No wonder that more than 100 students who passed through JNP are either pursuing Ph D programmes or have completed them. Some of them are faculty at institutions such as ICTS, JNCASR and IMSc. Finally, setting up of a science park at JNP was also Vishu's initiative. In the original plan drawn up in 1997, Antigravity Cottage that mimics the famous 'Mystery Spot' in the US and some other places had been envisaged. It was realized in 2016.

When the gravitational wave discovery by LIGO was announced last year, Vishu was elated. We have never seen him so high, thrilled by the possibility that soon there would be events where the quasi-normal modes would be even more strong. The profoundness of this discovery is in the realization that the black hole, which is purely a geometric object without any hard surface boundary, rings under perturbations like a material object. It is indeed the most telling and 'visible' defining property of a black hole. And Vishu was its discoverer. By all accounts, it is a discovery that will go down to textbooks. If that be the benchmark, there are only a few other contributions from India like the Raychaudhuri equation and Vaidya's radiating star that will make the grade. On the other hand, this discovery sits alongside the celebrated result that a black hole has no hair – the 'no hair' theorem. Most important of all, it is one of the few predictions that has been brilliantly verified by the observation of gravitational waves produced by the merger of two black holes. The observed profile has uncanny resemblance with what Vishu had plotted long back in 1970. There are very few predictions which are actually verified by experiment and observation. Vishu's black hole ringdown is one among them. This is the true and ultimate measure of a seminal insight.

We will miss you Vishu even as we try very hard to follow your favourite lines from Machado: '*Traveller there is no Path, Paths are made by Walking ...*'.

Vishu is survived by his wife Saraswati and two daughters Smitha and Namitha.


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NARESH DADHICH[1]
BALA IYER[2,*]

[1]*Inter-University Center for Astronomy and Astrophysics, Pune 411 007, India*
[2]*International Centre for Theoretical Sciences – TIFR, Bengaluru 560 089, India*
**e-mail*: *bala.iyer@icts.res.in*