

C V Vishveshwara (Vishu): the black hole man of India

C V Vishveshwara, or Vishu, is associated in the minds of 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. It was almost a year before he breathed his last on 16 Jan 2017 in Bengaluru. It was, therefore, most fortuitous that he could experience exhilaration and satisfaction of his contribution when the whole world was cheering and applauding. The black hole man of India will be remembered for a long time not only for his seminal contributions to understanding black holes but 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 via the activities at the Jawaharlal Nehru Planetarium and Bangalore Association for Science Education the inspiration lives on.

Vishveshwara was born on March 6, 1938 in Bangalore. He had his schooling there and then went on to Mysore University for further studies. He obtained the B.Sc.(Hons) degree in 1958 and the M.Sc. Degree from Central College of the then Mysore university in 1959. He then went to USA for higher studies. After getting his A.M. from Columbia University, New York, in 1964 he moved to University of Maryland from where he got his Ph.D. in 1968. His thesis advisor was Prof. C.W. Misner, the M of the directory of the universe, MTW. His thesis subject was "Stability of Schwarzschild Metric". After stints as a post doctoral fellow and a visiting faculty member, at Institute of Space Studies (1968-69), Boston University (1969-72), New York University (1972-74), University of Pittsburgh (1974-76), Vishu returned to Bangalore in 1976 and joined the Raman Research Institute. He moved from there, in December 1992, to the Indian Institute of Astrophysics, Bangalore 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 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 using 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 center on these topics and earned him the fond title of Black Holy 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 hole 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 pointwise 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 the claim to the non 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 Raman Research Institute and later Indian Institute of Astrophysics 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 ultracompact 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. Raychaudhuri. 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 set up 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 1980's. 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 the Indian researchers in the International Society of General Relativity and Gravitation (ISGRG) meetings was very limited. Creating an opportunity for the IAGRG community to interact with international experts on front line research areas in relativity and cosmology in India was needed 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! Staid Cambridge University Press was happy to include them in the proceedings and Vishu's cartoons in the ICGC proceedings a treat to look forward to. The series of cartoons on gravitational waves in those proceedings deserves 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 [5]."

Vishu's public lectures inspired a number of students all over the country. His lectures at Bangalore Science Forum, started by his Guru Dr H. Narsimiah, always drew huge numbers. He was a best-seller. And, he never disappointed the audience. Without diluting the profound ideas that he would discuss, he 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 1983-1993 to set up 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 1980's to get access to movie classics from National Film Archives in Pune and from the consulates like the German and French ones.

Jawaharlal Nehru Planetarium (JNP), Bangalore is a wonderful 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 Bangalore Association for Science Education (BASE) was set up by Vishu to systematically expose, attract and mentor students from school, high school 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. Via 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 very strong presence of experiments that make the programmes dynamic and vibrant and endearing to students. During the last twenty years, all these programmes have seen a steady growth in 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 hundred students who passed through JNP are either pursuing PhD programmes or have completed it. Some of them are faculty at institutions such as ICTS, JNCASR and IMSc. Finally, setting up of a science park at JNP was also his 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 realised 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 have been brilliantly verified by the observation of gravitational waves produced by merger of two black holes. The observed profile has very 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 those few. 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 favorite 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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