# Discussion meeting on 'Remembering C. V. Vishveshwara'*

Indian scientists recently celebrated the life and work of the late Prof. C. V. Vishveshwara and with a short discussion meeting, emphasizing his contributions to black hole physics, science popularization, and education. The morning session featured talks on Vishveshwara's scientific work, while the afternoon session focused on reminiscences, particularly about his work on science popularization and outreach.

Rajesh Gopakumar (International Centre for Theoretical Sciences, ICTS), inaugurated the proceedings, particularly thanking the speakers for coming at a short notice. He also remarked that Vishveshwara had been at ICTS almost exactly a year ago as part of the celebration of the detection of gravitational waves, where he gave his reminiscences about his fundamental work on black hole quasinormal modes. The video-recording of this talk is a popular feature on the ICTS YouTube channel – it was likely Vishveshwara's last but one talk.

The first scientific talk was by Bala Iyer (ICTS), who gave an overview of Vishveshwara's life and work, placing his work on black holes in the broad context of black hole physics. Iyer was one of Vishveshwara's three postdoctoral students (along with Sanjeev Dhurandhar and Sai Iyer), and then continued working with him when they were both faculty members at the Raman Research Institute (RRI), Bengaluru. One highlight was a discussion of Vishveshwara's early work elucidating the nature of the infinite redshift surface for black holes (showing that it coincided with the one-way membrane in the static case, but not in the rotating case), which is a regular part of textbooks today. Other highlights included his fundamental work on the stability of black holes, as well as the work on quasinormal modes. One of the large themes in Vishveshwara's work was the use of quantum mechanical techniques (e.g. scattering theory and effective potentials) to study black holes.

Iyer also discussed Vishveshwara's 'Sidney Harris-like' science cartoons, including a long series on gravitational waves. These cartoons made their initial appearance at the first International Conference on Gravitation and Cosmology meeting in Goa, when they would appear on the screen anonymously during breaks. Cambridge University Press was happy to include them in the conference proceedings, and they were a much-anticipated feature of the meetings.

The next talk was by Amitabh Virmani (Institute of Physics (IOP) Bhubaneshwar), who led a tour through the modern work on the stability of black holes that sprung from Vishveshwara's initial investigations, from mathematical proofs, to the AdS/CFT correspondence, gravitational wave astronomy and numerical relativity. While there are now proofs of stability of four-dimensional black holes for arbitrary perturbations (going beyond just mode stability), there has also been work on the instability of extreme charged or rotating black holes in four-dimensions and of non-extreme black objects in higher dimensions. Nonlinear stability is now an important area of study, and there is also fundamental mathematical work about the quasinormal modes remaining to be done (e.g. concerning their span).

B. S. Sathyaprakash (Penn State, USA) gave a remote talk entitled 'Black hole whispers', about the importance of quasinormal modes for gravitational wave astronomy and testing general relativity, particularly the no-hair theorem, emphasizing the prospects for future detectors. Sathyaprakash first heard Vishveshwara speak when he was a B Sc student in Bengaluru, and this was an important part of his decision to pursue science instead of music. He also promised Vishveshwara that one day he would be able to tell him about the detection of quasinormal modes (QNMs), a promise he was finally able to fulfil in 2016 – Vishveshwara's *Nature* paper on QNMs is the first QNM paper cited in the LIGO gravitational wave discovery paper. Vishveshwara was quite excited about future gravitational wave detections, particularly about the prospects for events with higher-signal-to-noise ratios (SNRs) in the ringdown, as Bala Iyer mentioned.

Sathyaprakash explained the now-standard no-hair theorem test involving measuring the frequency and damping time of two or more QNMs. The frequencies and damping times of all the QNMs of a generic (spinning) Kerr black hole only depend on its mass and spin. Thus, measuring one QNM (of known order, e.g. the dominant, least damped one) determines the mass and spin of the black hole, while additional measurements give constraints on the Kerrness of the space–time. (While black holes can in principle have electric charge, and thus be described by the Kerr–Newman solution, astrophysical black holes are expected to have negligible charge.) One will start to get the relatively high SNRs needed to perform such a test with advanced LIGO at design sensitivity, but for truly sensitive tests, one will need further upgrades and a network of detectors (including LIGO-India), or to go into space and detect gravitational waves from the coalescences of supermassive black hole binaries, as the Laser Interferometer Space Antenna (LISA) mission proposes to do.

Rajesh Nayak (IISER, Kolkata), one of Vishveshwara's three Ph D students, along with Biplab Bhawal and B. S. Ramachandra, gave the last talk of the scientific session. Nayak discussed the application of the Frenet–Serret frame (the natural frame for a non-geodesic curve) to the study of space–times in general relativity. Vishveshwara and collaborators used the Frenet–Serret frame to study a variety of problems, from the motion of particles in uniform electric fields, to higher-dimensional space–time. In particular, Iyer and Vishveshwara applied Frenet–Serret to study gyroscopic precession. In this massive paper, one sees some of Vishveshwara's playful names for scientific quantities, such as Globally Hypersurface Orthogonal Stationary Trajectories (GHOSTs). GHOSTs are similar to Newtonian rest frames, and can be used to define gravitational Coriolis and centrifugal forces, as well as to

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give a new definition of gravitomagnetic fields.

The reminiscence session began by showing a video created by Vishveshwara's two daughters, Smitha (UIUC) and Namitha, who regretted their inability to attend the meeting in person. They started by talking about Vishveswara's father, C. K. Venkataramayya, who was a scholar and advisor to the Maharajah of Mysore. They then gave anecdotes from Vishveshwara's life, emphasizing that he 'lived Einstein' and gave his family a firm grounding in science, and also that the planetarium was his third child. Some more of Vishveshwara's playful side was revealed by his self-given nickname LOU Quasimodo. Here LOU = Lord Of the Universe (from Vishveshwara), and the Quasimodo (for quasinormal mode) part came from seeing someone playing Quasimodo during a visit to Notre Dame in Paris. As mentioned in Iyer's talk, Vishveshwara also referred to himself as the 'Quasimodo of black holes', and the 'black holy man of India' (punning on his usual epithet of the 'black hole man of India'). Smitha and Namitha also discussed Vishveshwara's deep knowledge of music, both Western and Indian classical, and his ability to identify the raga of any Indian piece, or the specific Western piece being played, after hearing only a few notes.

B. S. Shylaja (Jawaharlal Nehru Planetarium, Bengaluru) discussed Vishveshwara's time at the Jawaharlal Nehru Planetarium. He was the founding director of the planetarium, when it was just an empty building. The first programme was entitled 'Our Sun and His Family', and featured slide projections of artwork and specially composed music, with in-house special effects complementing the ones that were part of the Zeiss projector. These collaborations with artists and musicians continued throughout Vishveshwara's tenure. Shylaja related Vishveshwara's tip for planetarium programmes: 'The secret of success: the opening should be grand – the end should be memorable! The two should be as close to each other as possible!' and his management slogan DDDDD: Don't Discuss and Delay; Decide and Do. (Vishveshwara referred to newspapers as DDD, for Daily Dose of Depression.) Shylaja also discussed the many planetarium outreach programmes instituted by Vishveshwara, including the Science Park and Know Your Stars programme, as well as the education programmes presented in detail in the next talk. She ended with an anecdote from Vishveshwara's time as Ph D student in Maryland, USA, that did not make it into the Kannada biography that she wrote. This concerned about how Vishveshwara discovered that the mysterious signals detected nightly by Joseph Weber's gravitational wave detector were due to a security guard hitting his stick on the ground.

K. Vijay Kumar (ICTS) discussed the Research Education Advancement Programme (REAP), as well as the SEED (Science Education in Early Development) and SOW (Science Over Weekends) programmes, which together make up the Tree of Learning, with REAP at the apex. This was all part of Vishveshwara's plan to have the planetarium as a centre for science education, not just a nice projector. Vijay Kumar was an early REAP member, back when the programme was more informal. It is now a formal three-year programme, emphasizing solving problems and writing papers, and has been joined by Bio-REAP in the biological sciences. Vishveshwara was quite pleased with the success of REAP. The entire goal of the Tree of Learning is to have a pipeline that excites students about science, e.g. with public talks, and then provides them an opportunity to participate in research and get trained on the way to a Ph D, and potentially eventually a faculty position. Vijay Kumar also played an extract from Vishveshwara's last video-recorded appearance, from National Science Day celebrations almost exactly a year before this meeting, where he discussed the importance of solving problems, as opposed to rote learning.

There were informal remarks from Srikanth Sastry (JNCASR, Bengaluru) and C. S. Aravinda (TIFR-CAM), who credited Vishveshwara as inspiring them to take up careers in physics and mathematics respectively. Aravinda in particular remembered Vishveshwara arranging for him to look at the copy of Newton's *Principia* at RRI after he heard Vishveshwara mention this copy in a talk. Vishveshwara also did this on a separate occasion for Aravinda's brother.

The final presentation was from B. G. Gujjar, an artist who had worked with Vishveshwara for the planetarium. Gujjar started by drawing a caricature of Vishveshwara (which he donated to ICTS), in which he had treated Vishveshwara's eyes as a focal point. This caricature is particularly appropriate because Vishveshwara would hold sessions for students at the planetarium, where anecdotes from scientists' lives were given, illustrated with caricatures. Vishveshwara originally contacted Gujjar for making illustrations for the *Bulletin of Sciences*, and they then had a long working relationship. Gujjar showed a wide variety of his own cartoons covering scientific and political/social matters, as well as some of Vishveshwara's cartoons and caricatures. The presentation ended with some of Gujjar's planetarium cartoons illustrating, for example, the Pleiades with both the chicks from Indian mythology and the seven sisters from Greek mythology, electron degeneracy pressure, and the transit of Venus.

The meeting ended with brief remarks from Vishveshwara's wife, Saraswathi (IISc, Bengaluru).

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